CDF: B physics performance & trigger – operational experience

Beauty 2006

The 11th International Conference on
B-Physics at Hadron Machines

September 25th-29th, 2006

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INFN Frascati

On behalf of the CDF collaboration

Outline

Quick CDF detector overview

CDF Trigger architecture

XFT: Level 1 track trigger (lepton triggers)

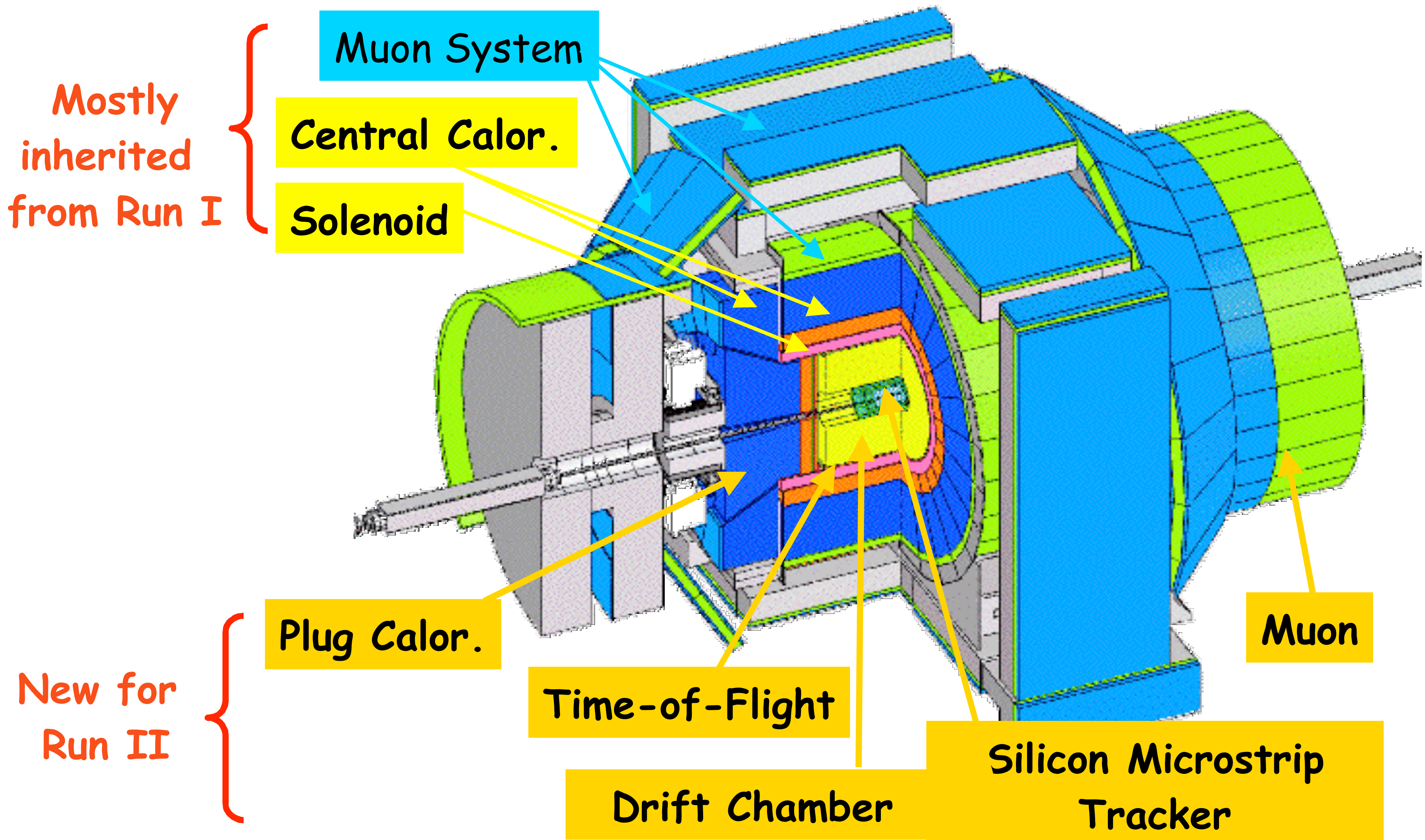
SVT: Level 2 silicon vertex trigger

CDF Trigger strategy for B Physics

Problems at high luminosity (upgrades)

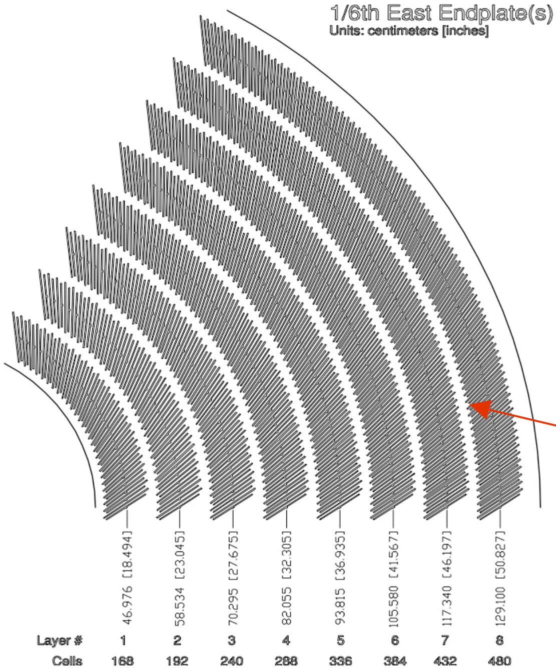
Conclusions

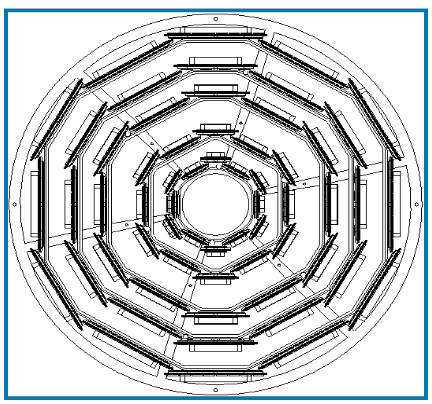
The CDF detector



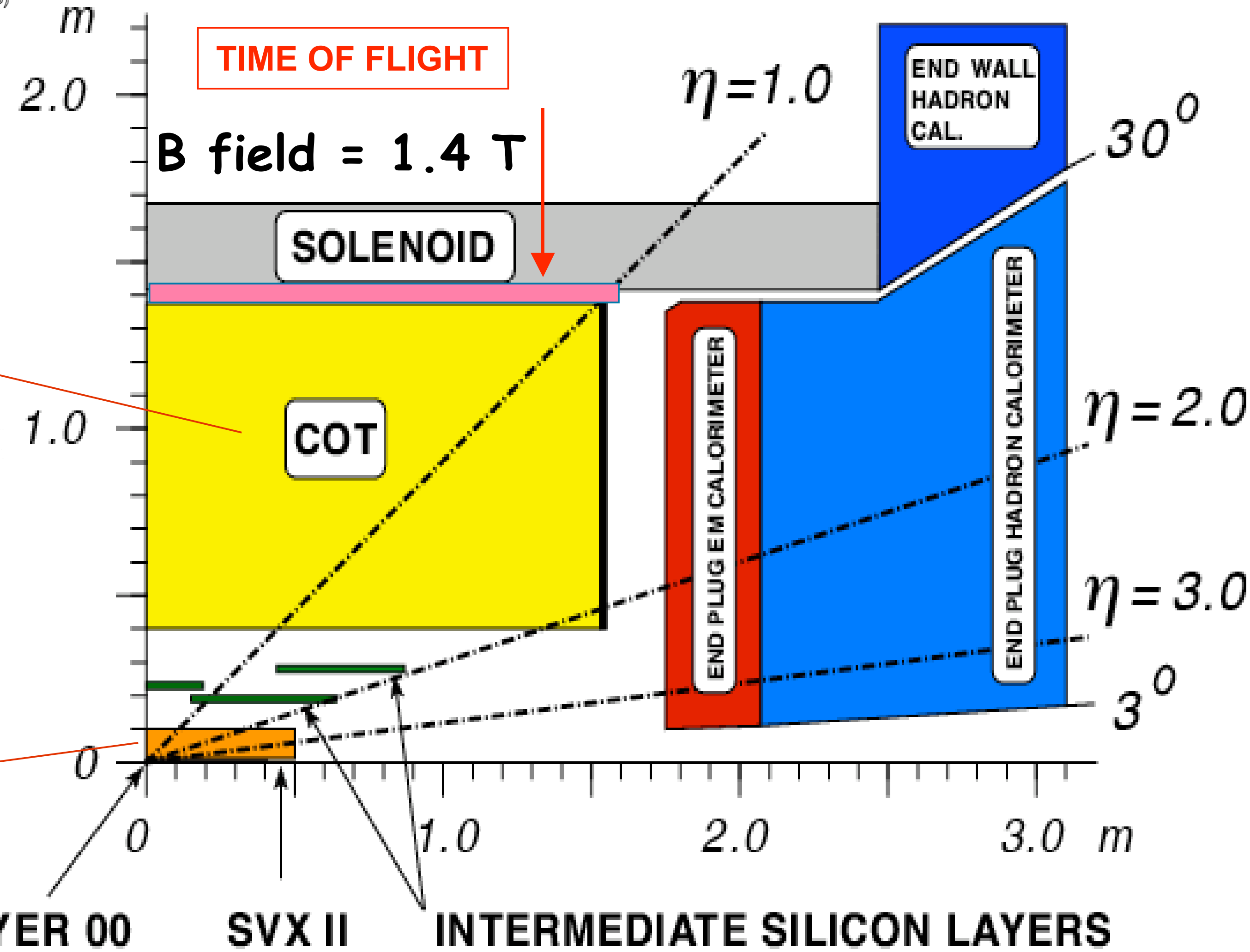
The CDF Tracker

Transverse view

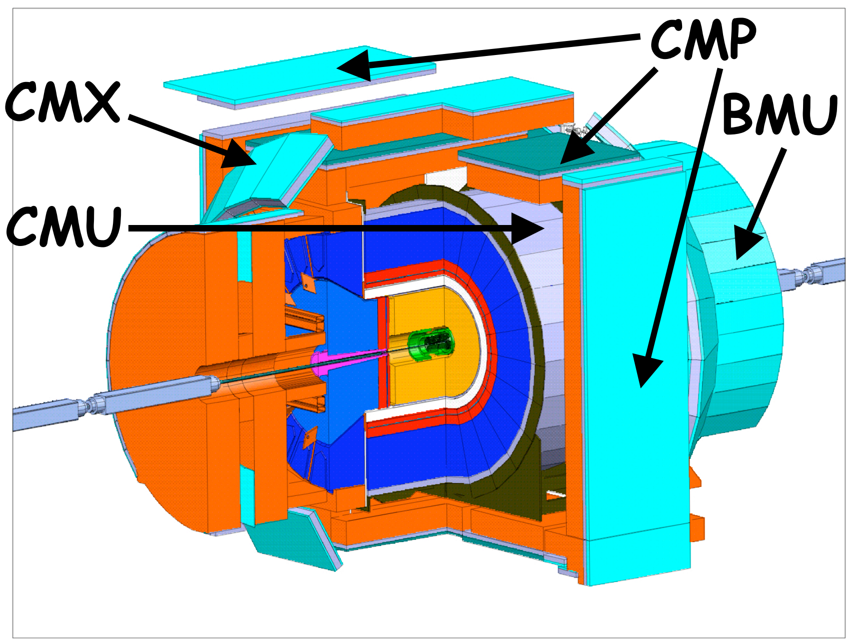




Longitudinal view

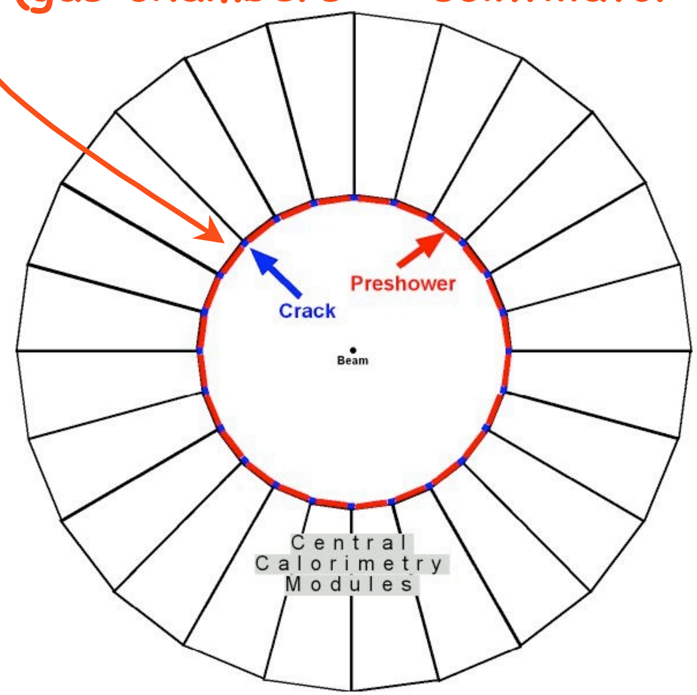


Lepton detectors (muons, electrons)

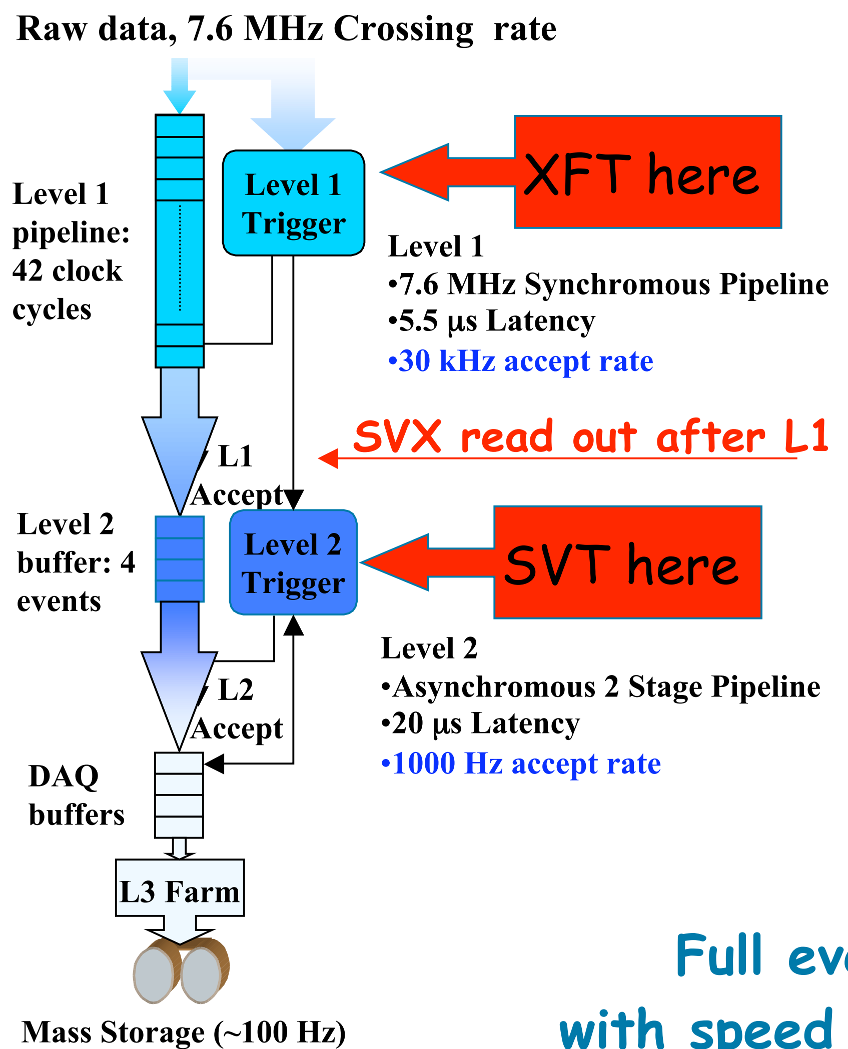


CMU/CMP $|\eta|<0.6$
CMX $0.6 < |\eta| < 1.0$
BMU $1.0 < |\eta| < 1.5$

CEM calorimeter: scintillator/lead
- $\eta \times \phi$ towers 0.11×0.26
- ~ 20 radiation length deep
- Position detector at shower max
- Preshower recently upgraded (gas chambers → scintillator bars)



CDF Trigger Architecture



Drift chamber tracking

Lepton reco/track matching

...

Silicon tracking

Secondary vertex selection

...

CPU farm

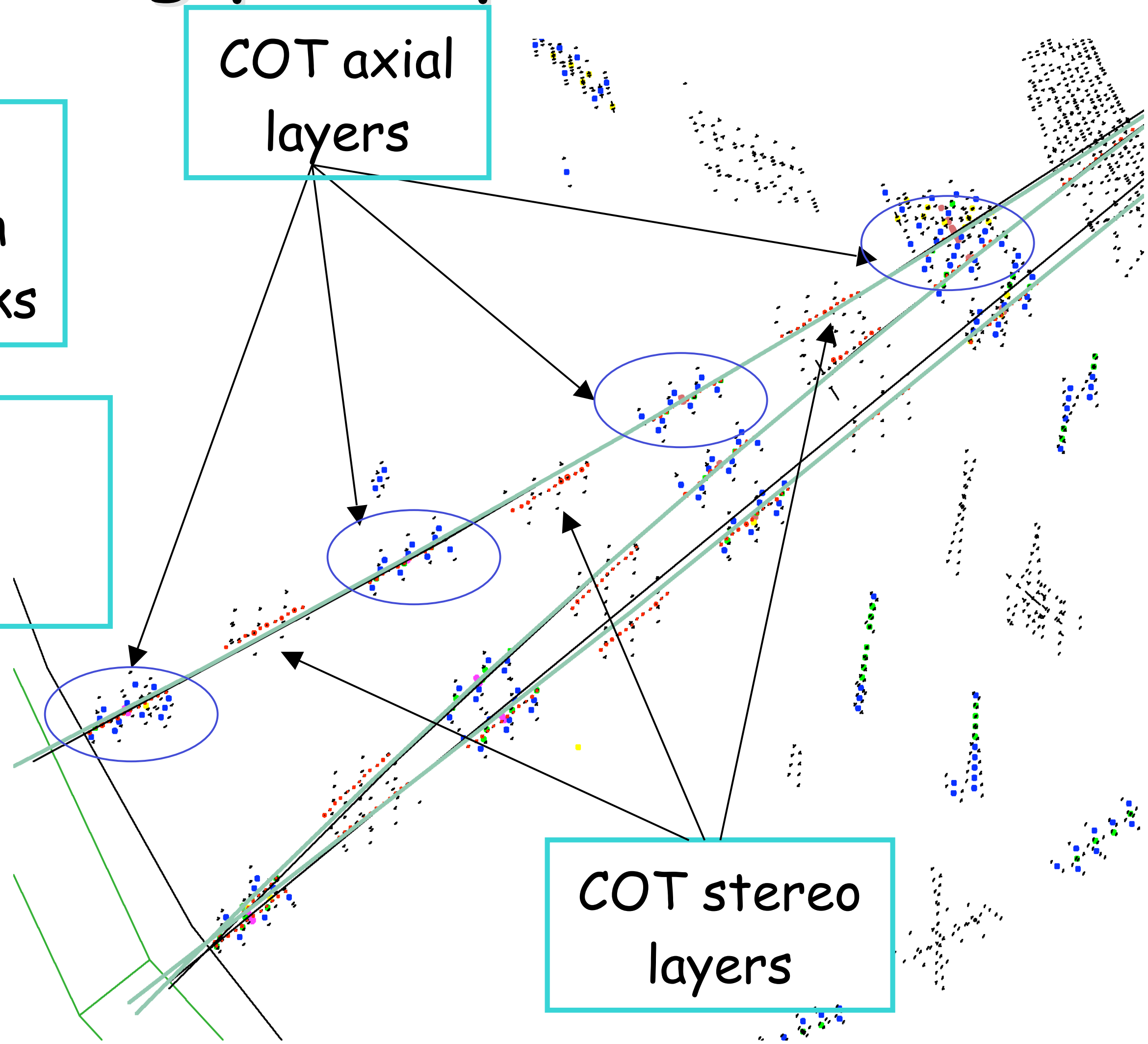
Full event reconstruction

with speed optimized offline code

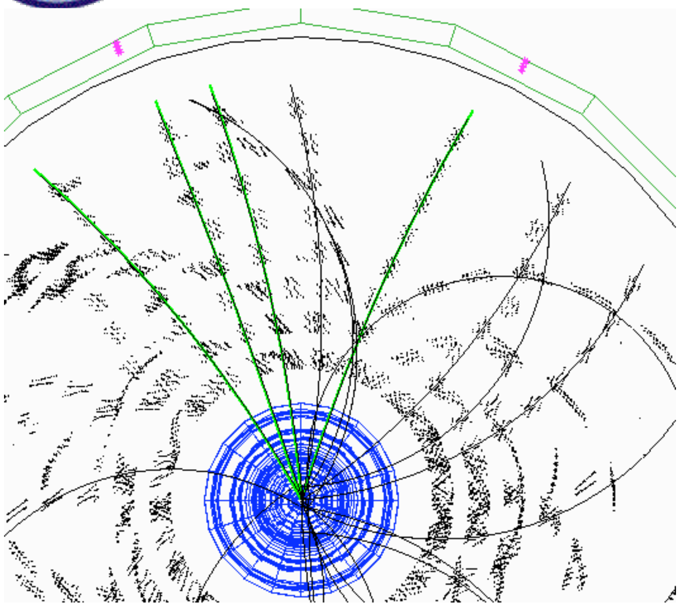
eXtremelyFastTracker
working principle

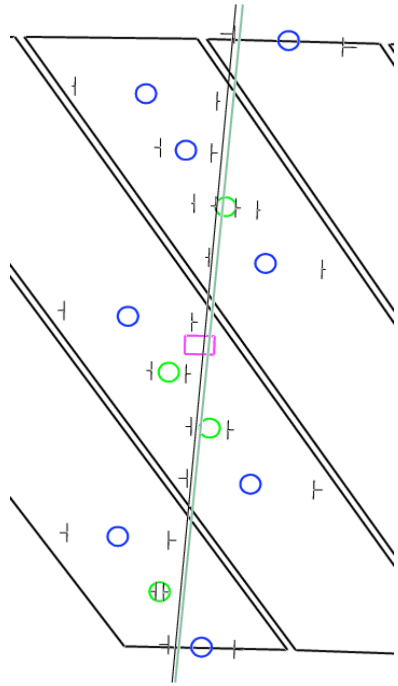
Good hit patterns are identified as segments, then segments are linked as tracks

XFT 3D upgrade
Add info from stereo layers
(see later)



Level 1 drift chamber trigger (XFT)





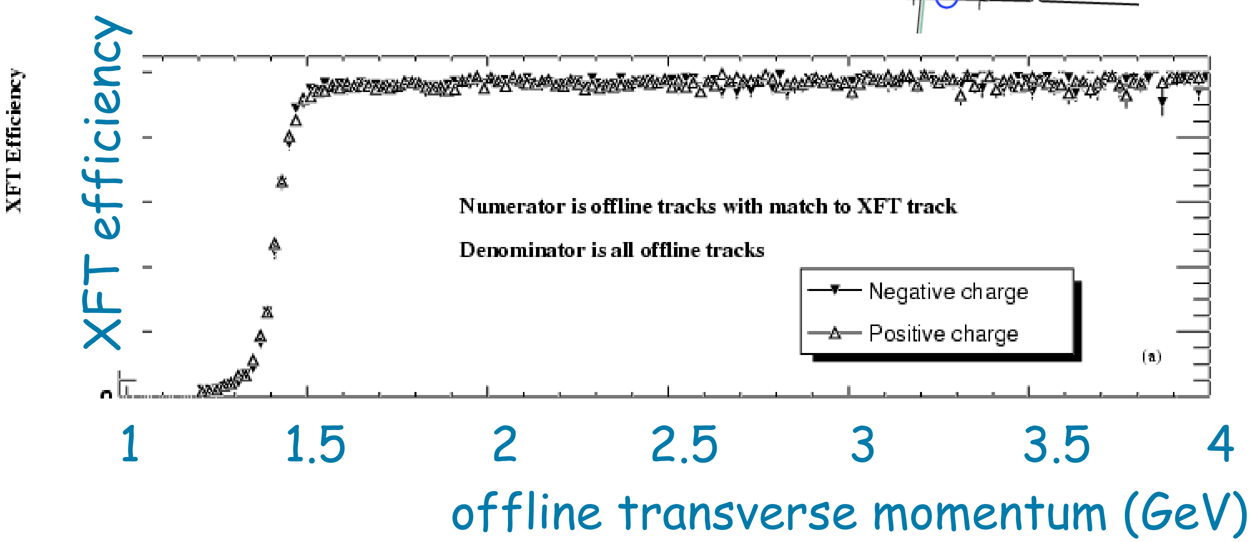
Finds p_T>1.5 GeV tracks in 1.9 μs

For every bunch crossing (132 ns)!

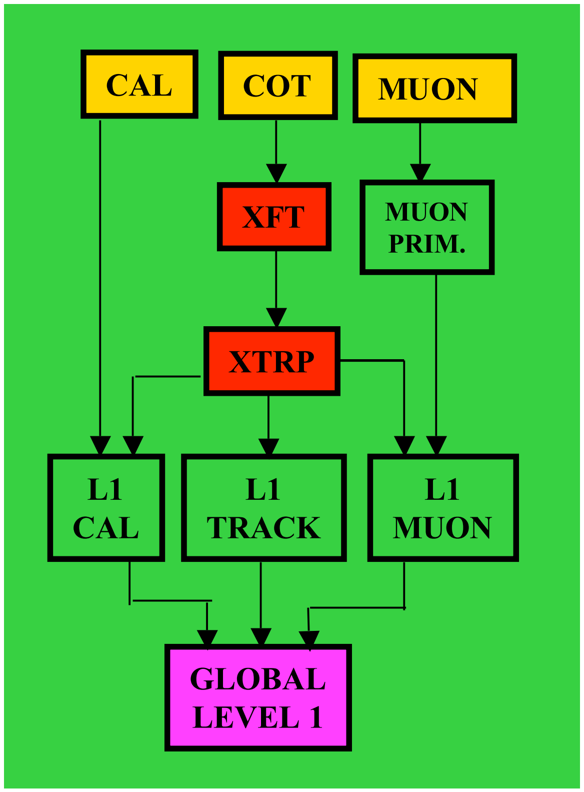
$\sigma(1/p_T)$ = 1.7%/GeV

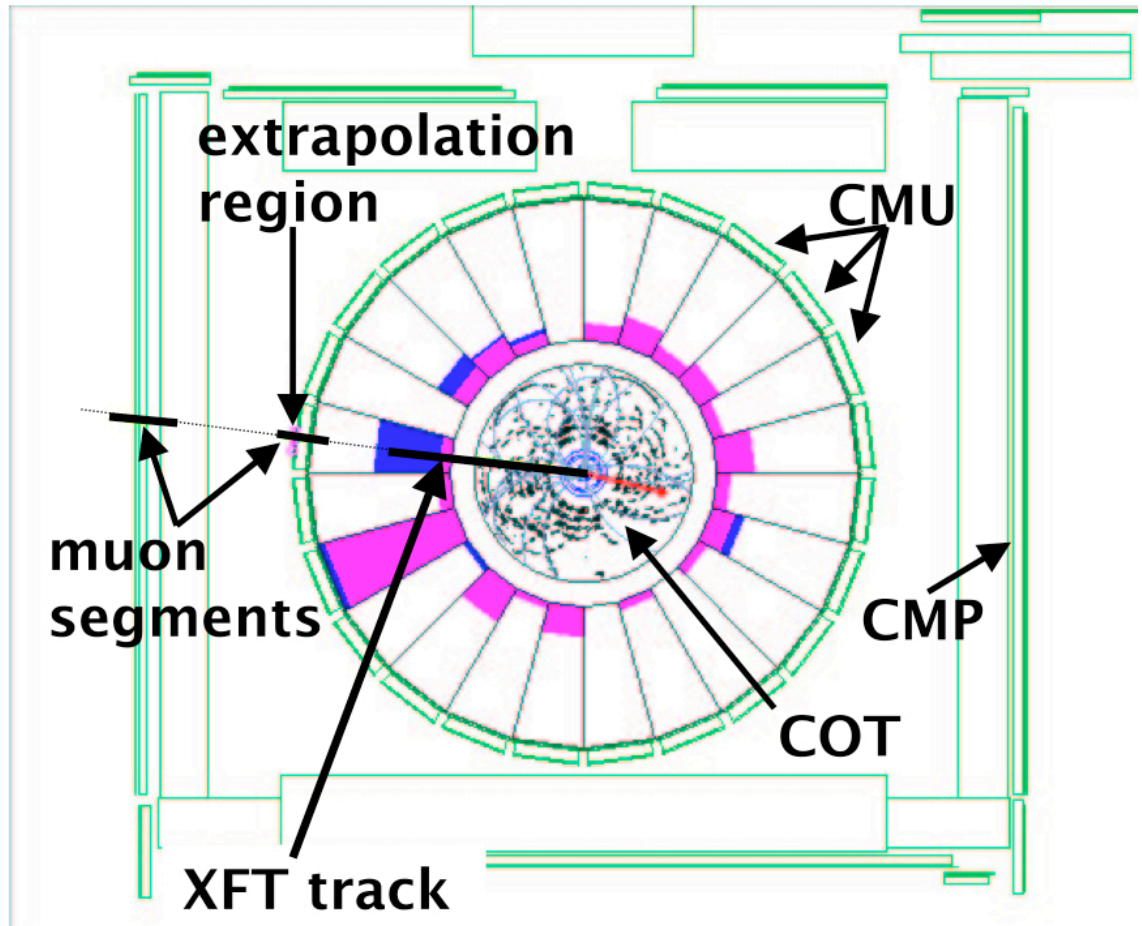
$\sigma(\phi_0)$ = 5 mrad

96% efficiency



Lepton triggers @ level 1

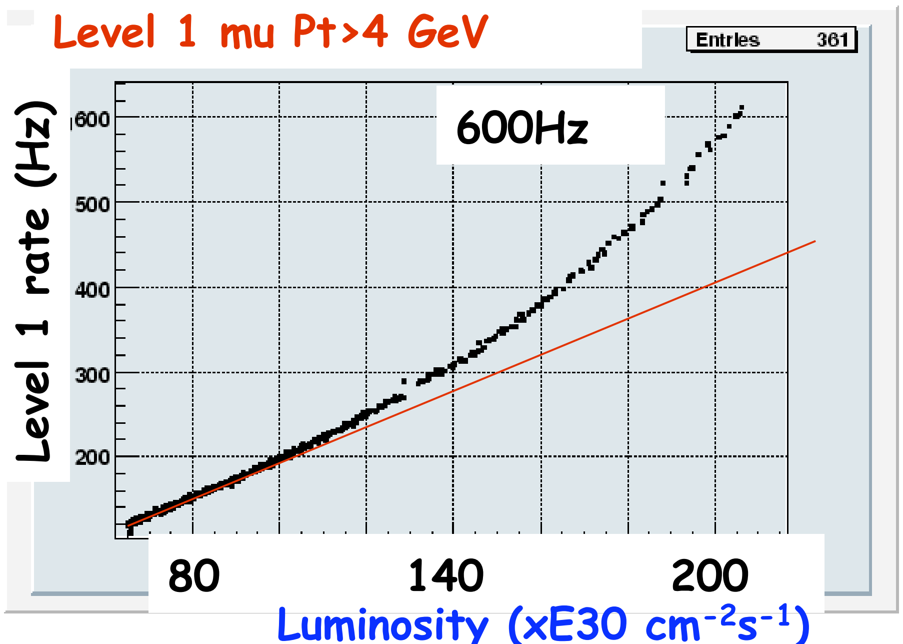




Lepton triggers

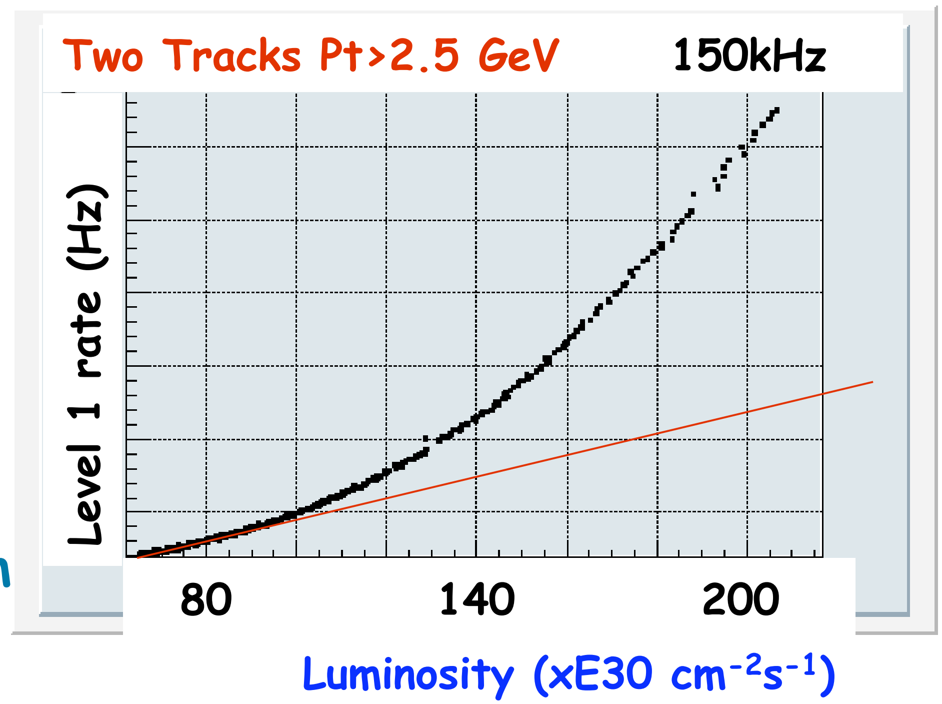
match between a muon stub or
calorimeter signal with an XFT track extrapolated by the XTRP

Level 1 performances



End of store ← injection

Inclusive muon Pt>4 @ level 1
Low rate 600Hz @ peak lumi
Compare with 30kHz bandwidth



Inclusive Two Track @ level 1
Huge rate 150kHz @ peak lumi
Compare with 30kHz bandwidth
Use more selective trigger @high lum
Important contribution from fakes

Level 1/2 bandwidth share

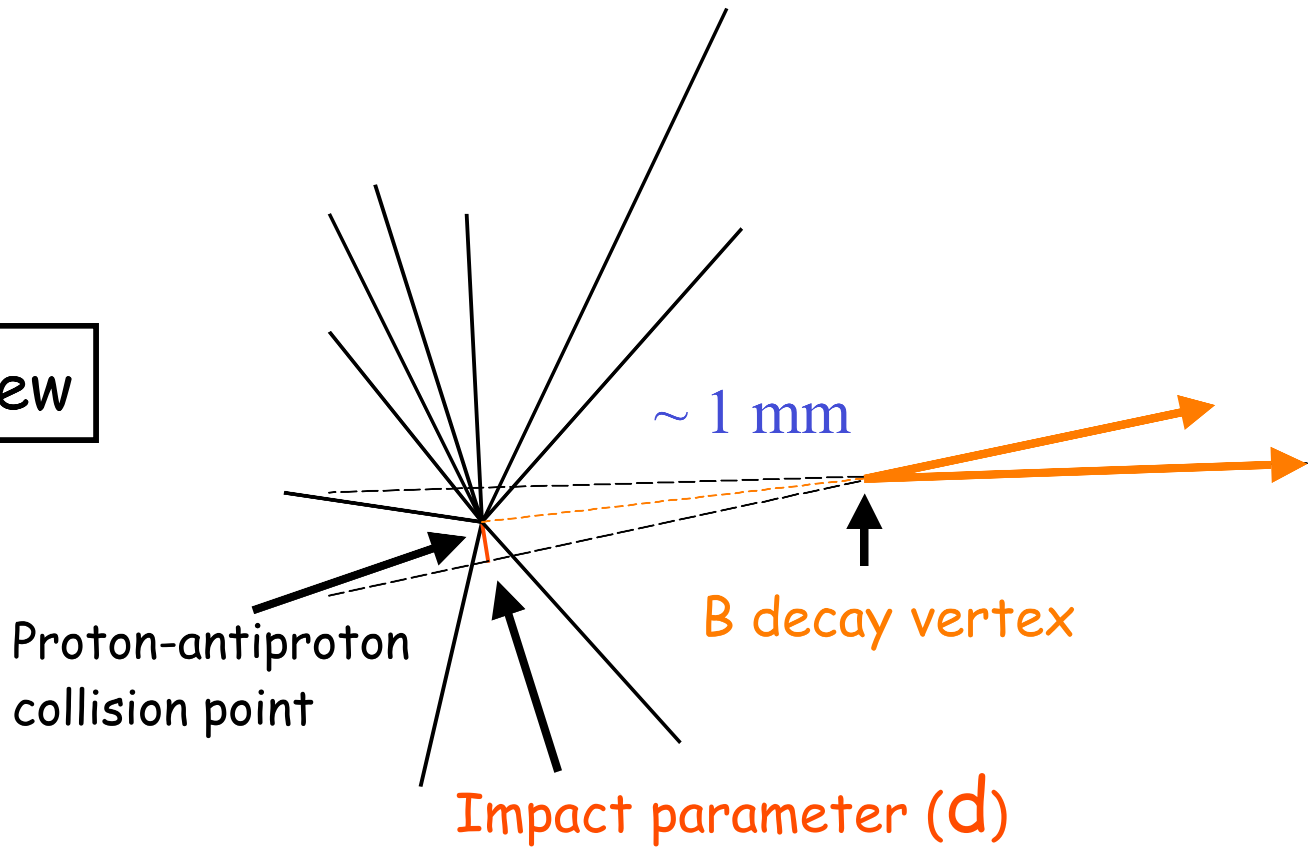
- Level 1 bandwidth ~30kHz
  - Mostly used by Two Track Triggers
    - Very inclusive signature
    - High trigger rate
  - Only a small fraction needed for high-pt triggers
    - Lepton/jets are much more selective
    - Low trigger rate

- Level 2 bandwidth ~1000Hz
  - Largely used by high-pt triggers
    - Mostly refine Level 1 selection
    - Limited rejection power
    - Will be improved soon (XFT 3D upgrade)
  - Two Track Triggers only use a small fraction of Level 2 b/w
    - Identify secondary vertexes
    - High rejection power

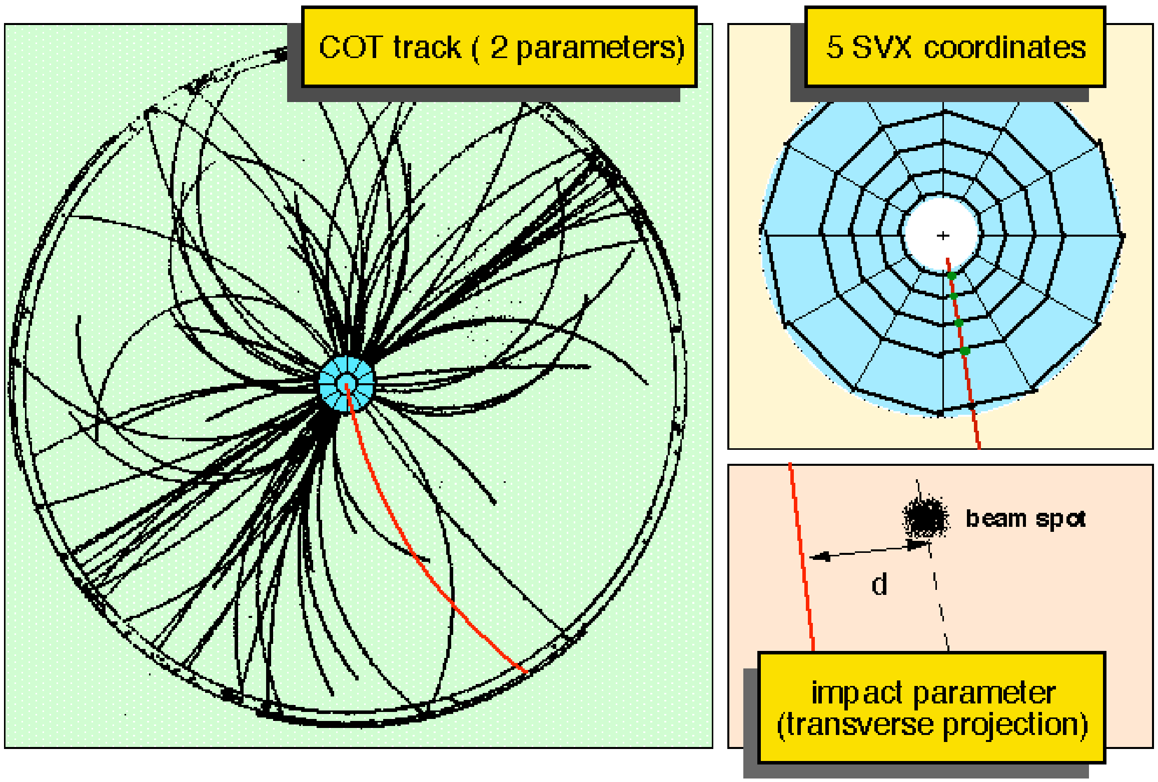
SiliconVertexTrigger

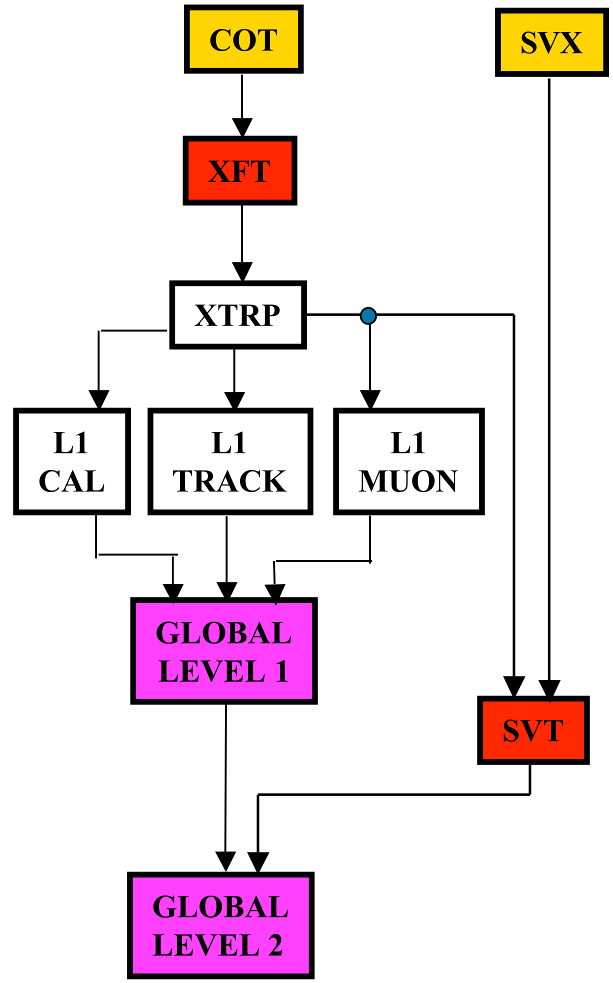
Exploit lifetime to select b & c decays

Transverse view



SVT: Input & Output





Inputs:

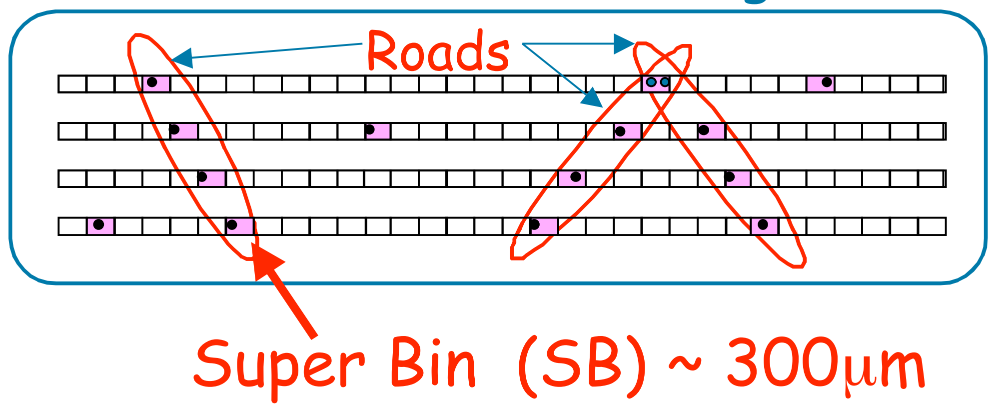
- L1 tracks from XFT (ϕ, pT)
- digitized pulse heights from SVX II

Outputs:

- reconstructed tracks (d, ϕ, pT)

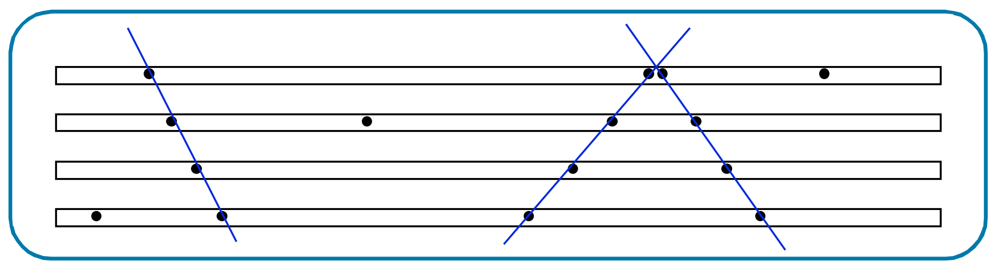
Tracking in 2 steps

Pattern matching



1. Find low resolution track candidates called "roads". Solve most of the pattern recognition

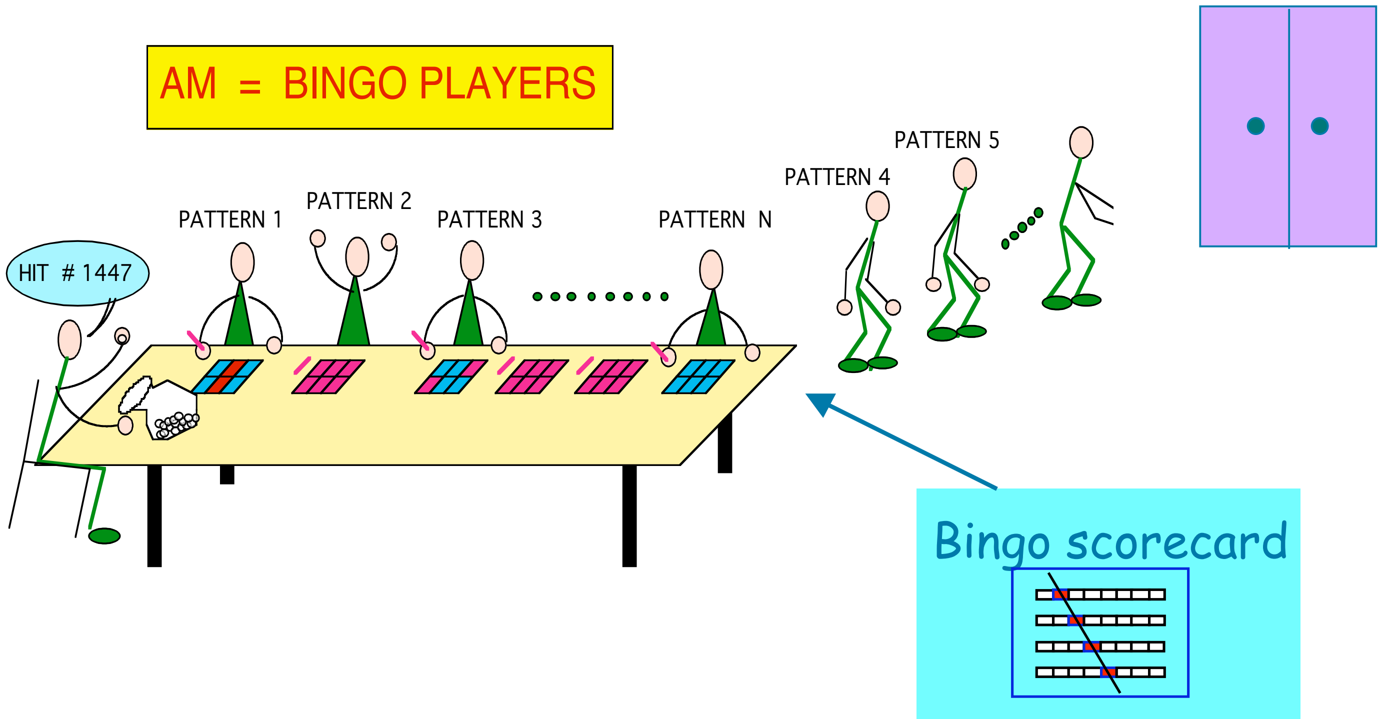
Linearized Track Fitting



2. Then fit tracks inside roads. Thanks to 1st step it is much easier

AM: Associative Memory

Implement pattern matching

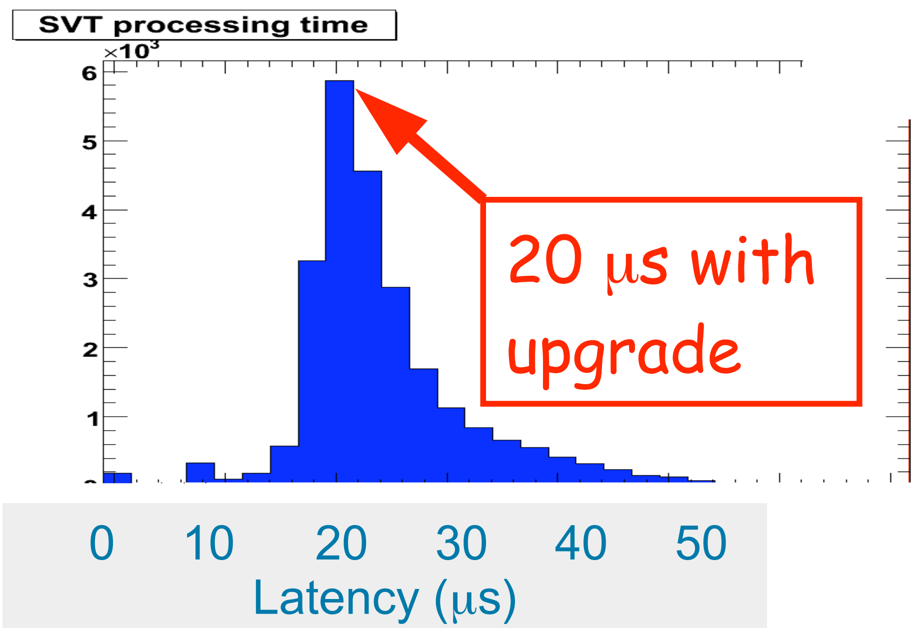


- **Dedicated device: maximum parallelism**
- **Each pattern with private comparator**
- **Track search during detector readout**

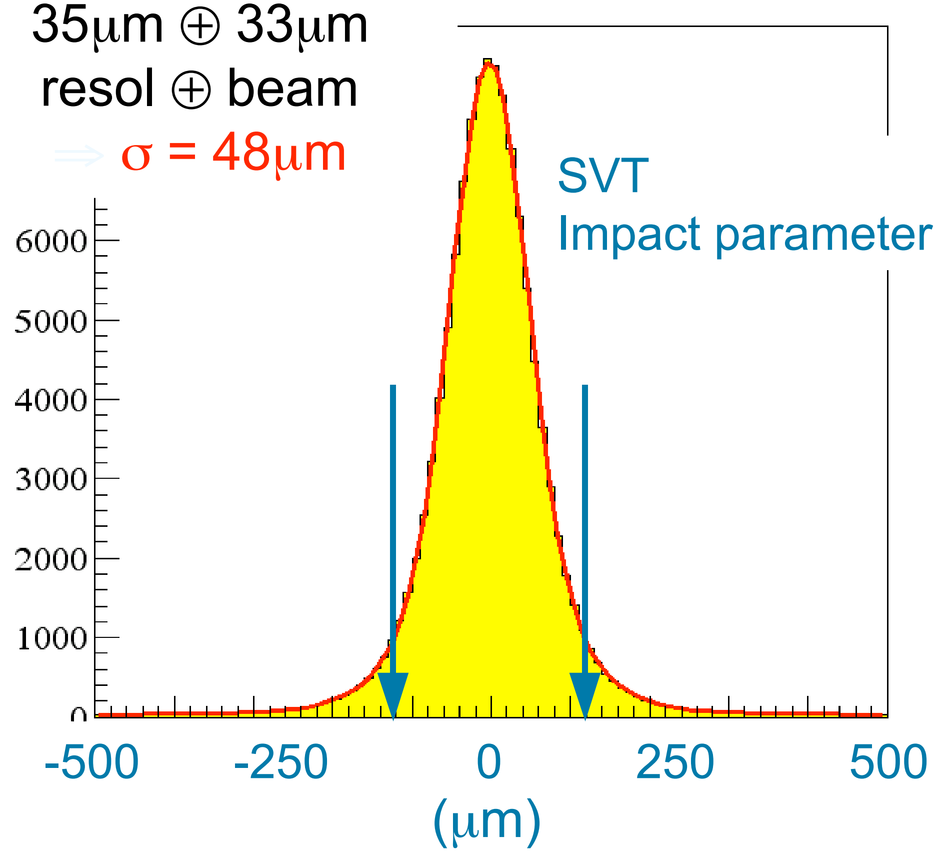
Trans. Nucl. Sci. 53, 4, Part 2, 2428 (2006)

SVT Performance @ 1x10^{32}

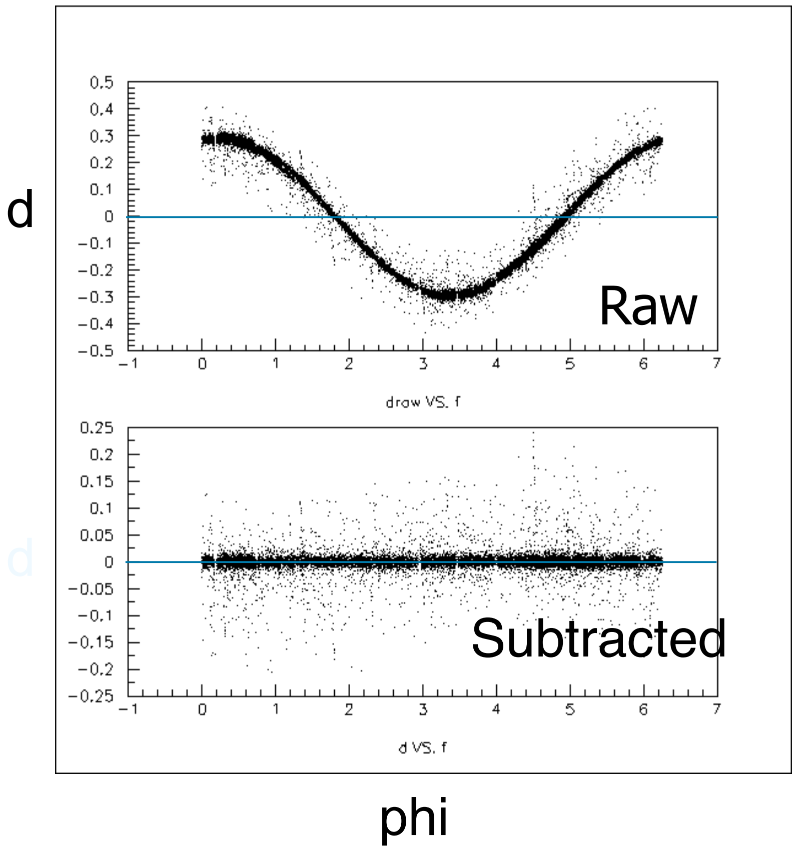
90% efficient given a fiducial offline track with SVX hits in 4 layers

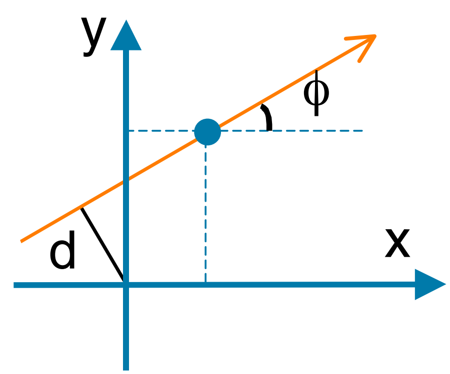


35µm ⊕ 33µm
resol ⊕ beam
⇒ σ = 48µm

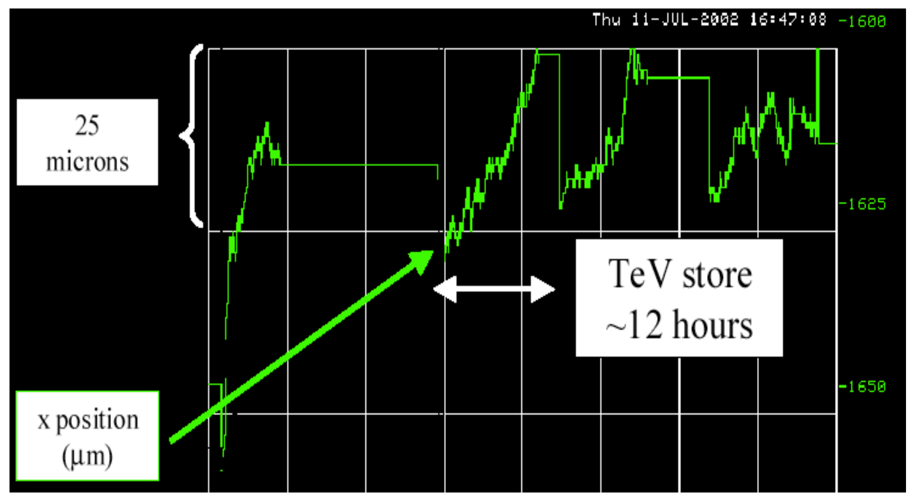


Online beamline fit & correction





$$\langle d \rangle = Y_{beam}\cos\phi - X_{beam}\sin\phi$$



Measure beam width as well --> input to Accelerator Division

Track Triggers and B Physics

Di-Muon (J/ψ)

$P_t(\mu) > 1.5$ GeV

J/ψ modes down to low $P_t(J/\psi)$ (~ 0 GeV)

$\psi(2S)$, $X(3872) \rightarrow J/\psi\pi\pi$ (quarkonia)

$B_s \rightarrow J/\psi\,\phi$, $B_{u,d} \rightarrow J/\psi\,K^{(*)}{}_s$ $\Lambda_b \rightarrow J/\psi\,\Lambda$ (masses, lifetimes, mix. calibration)

$B_{s,d} \rightarrow \mu\mu$ (rare decays)

$\Upsilon \rightarrow \mu\mu$

Bc (part.rec.$B \rightarrow J/\psi\, lX$)

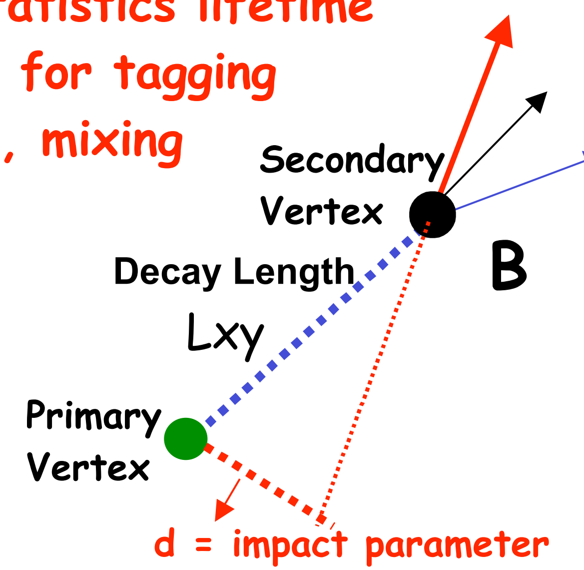
Displaced trk + lepton (e, μ)

IP(trk) > 120μm

Pt(lepton) > 4 GeV

Semileptonic modes

High statistics lifetime Sample for tagging studies, mixing



2-Track Trig.

Pt(trk) > 2 GeV

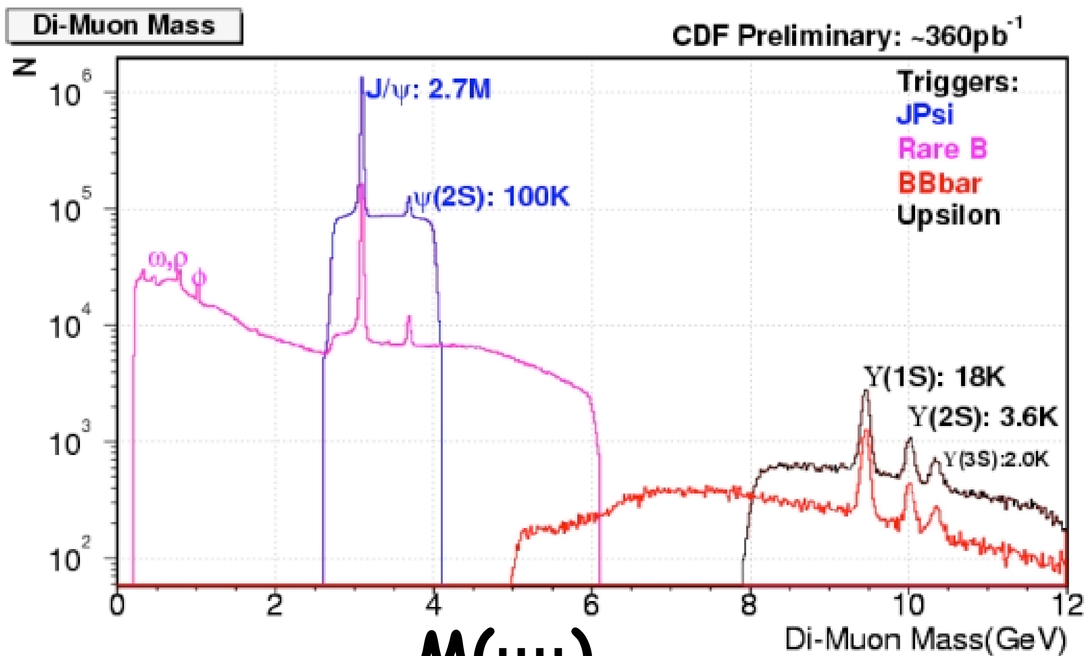
IP(trk) > 100 μm

Fully hadronic modes

- CP asymmetry in 2-body charmless decays
- B_s mixing
- Charm physics

see B. Reisert's talk tomorrow

Dimuon Trigger Yields

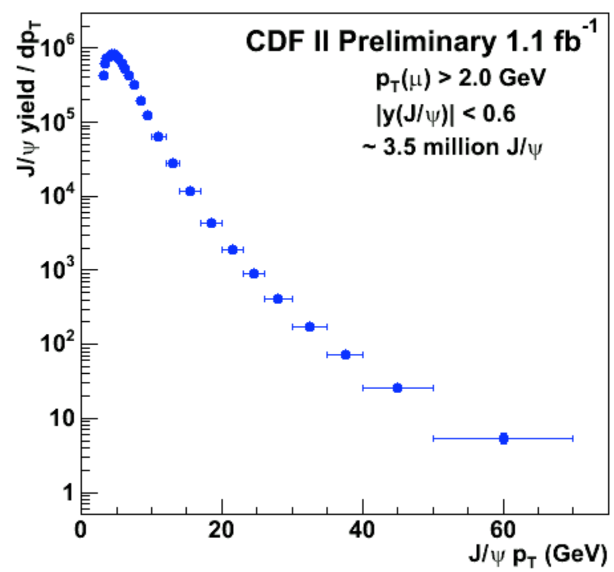


M(μμ)

Mass spectrum
for different
dimuon trigger paths

3.5M J/ψ Yield

Also very important for calibrations



Hadronic B decays

Two trigger paths

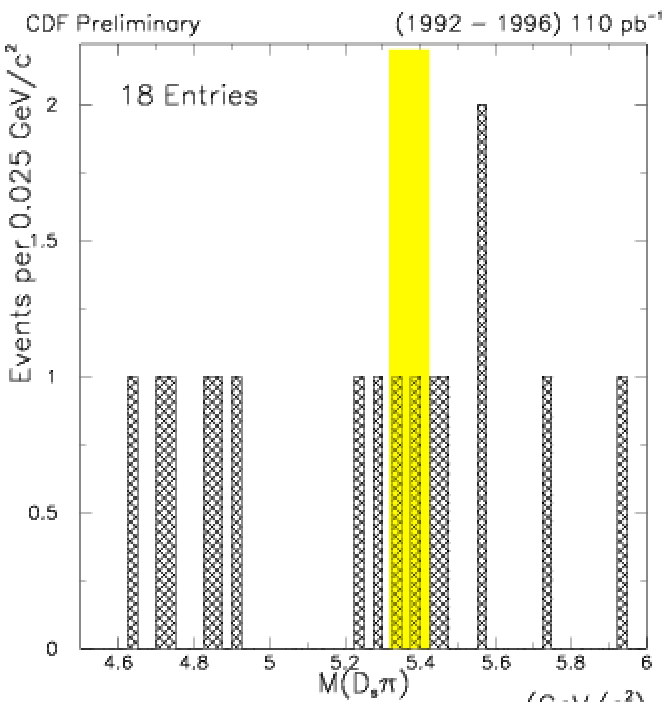
L1	Two XFT tracks $P_t > 2$ GeV; $P_{t1} + P_{t2} > 5.5$ GeV $\Delta\phi < 135°$	
	Two body decays	Many body decays
L2	100 μm$<d_0<$1mm for both tracks Validation of L1 cuts with $\Delta\phi>20°$ Lxy > 200 μm $d_0(B)<140$ μm	100 μm$<d_0<$1mm for both tracks Validation of L1 cuts with $\Delta\phi>2°$ Lxy > 200 μm $\cancel{d_0(B)<140\ \mu m}$
	B -> h h'	B_s mixing

Essential for Bs mixing measurement! (A. Belloni Monday)

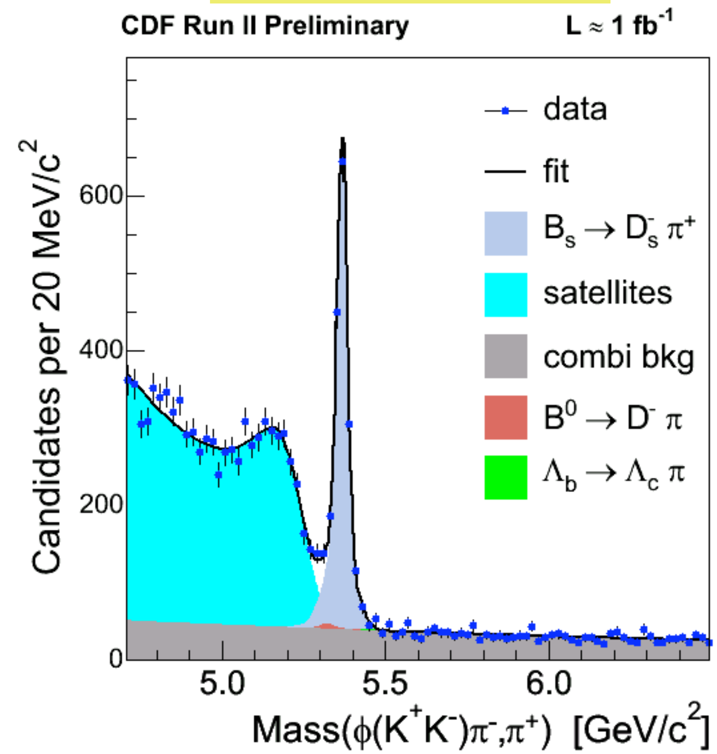
The Displaced Track Trigger

- Run I collected O(1) $B_s \to D_s\pi$ (all D_s modes)
- Run II collected ~2000 $B_s \to D_s\pi$ ($D_s \to \phi[\to K^+K^-]\,\pi$)
- Compare with only 10x integrated luminosity!

Without SVT

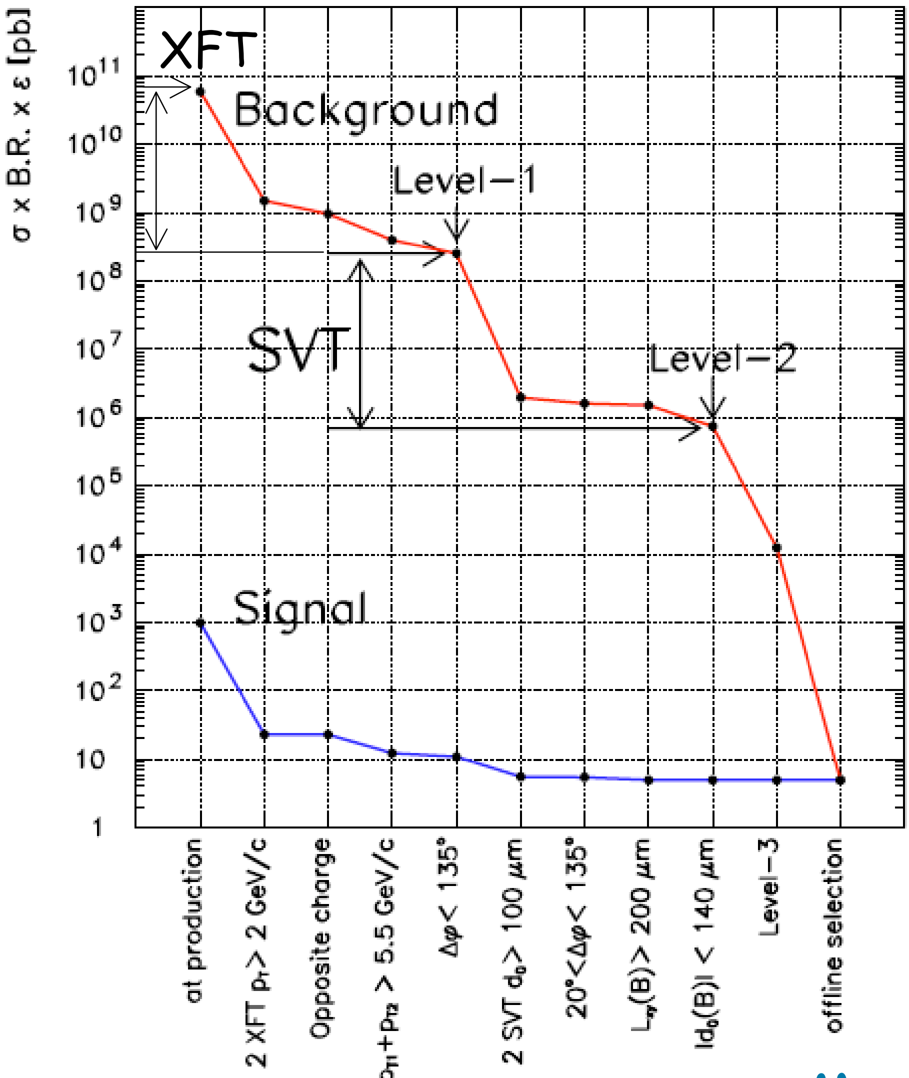


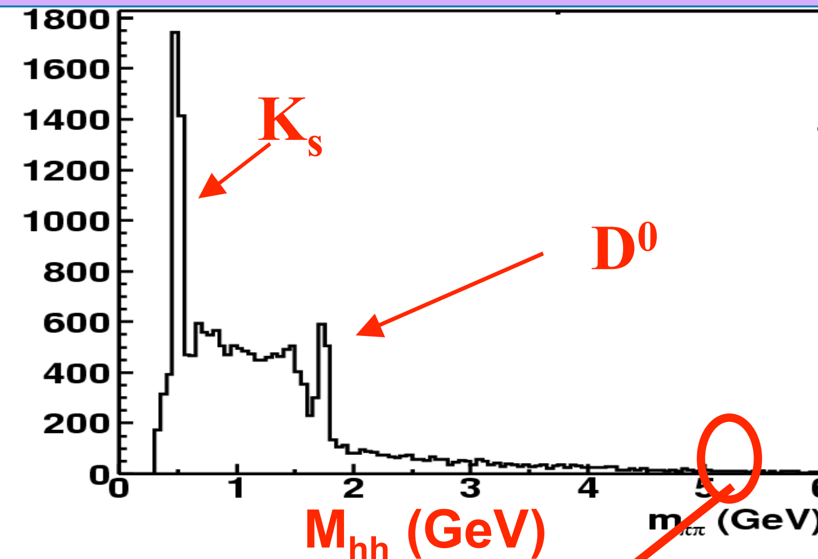
With SVT

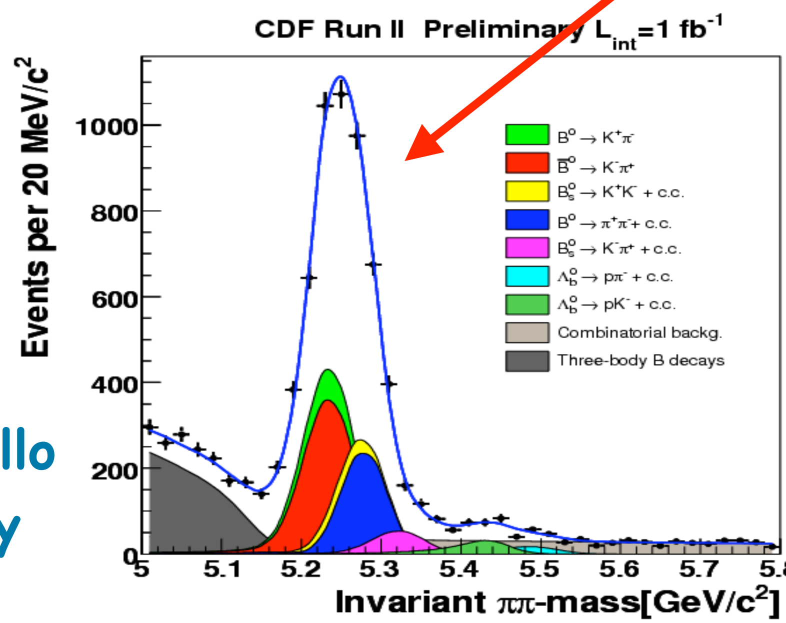


$B^0 \to$ had + had Trigger

The XFT+SVT advantage: 5 orders of magnitude



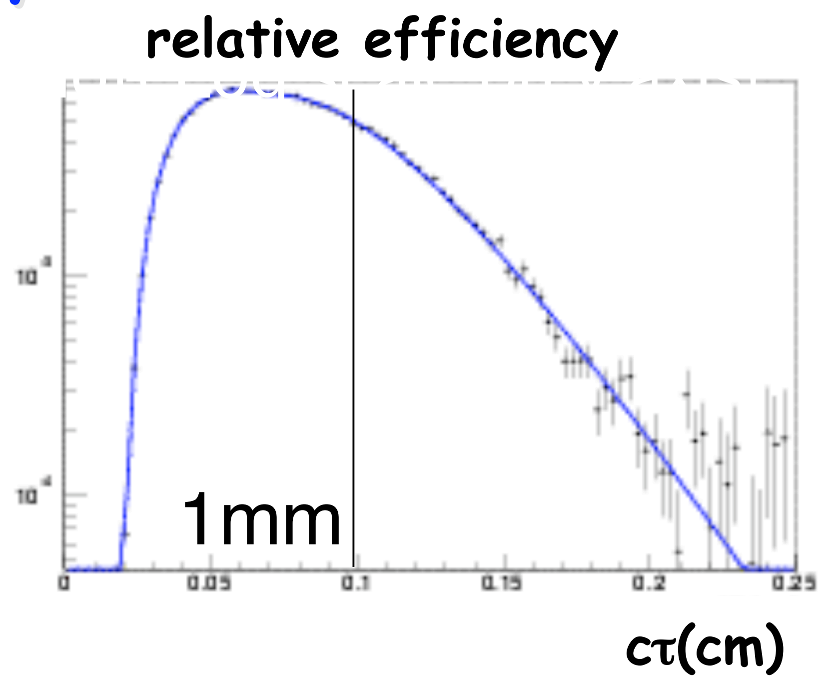




M. Morello
Tuesday

cτ efficiency curve

- Two Track Trigger requires:
  - 100 μm < i.p. < 1 mm
- Efficiency drops significantly beyond ~1mm



- Affects lifetime measurements
  - Use bit level simulation to reproduce it accurately w/ MC
  - Statistical power of events reduced to ~30%
    - Because of shorter lever arm for lifetime measurement
    - Analytical calculation J. Rademaker NIMA 45856
    - Considering to increase cut to 2mm
      - Would increase statistical power back to ~75%

Triggering at high luminosity

DAQ/trigger designed for L=100E30 $cm^{-2}s^{-1}$(@132ns)
now L=230E30 $cm^{-2}s^{-1}$(@396ns) and growing fast

Harsh conditions:

- Multiple $p\bar{p}$ interactions per bunch crossing, larger COT occupancy, more XFT fakes, larger trigger rates.

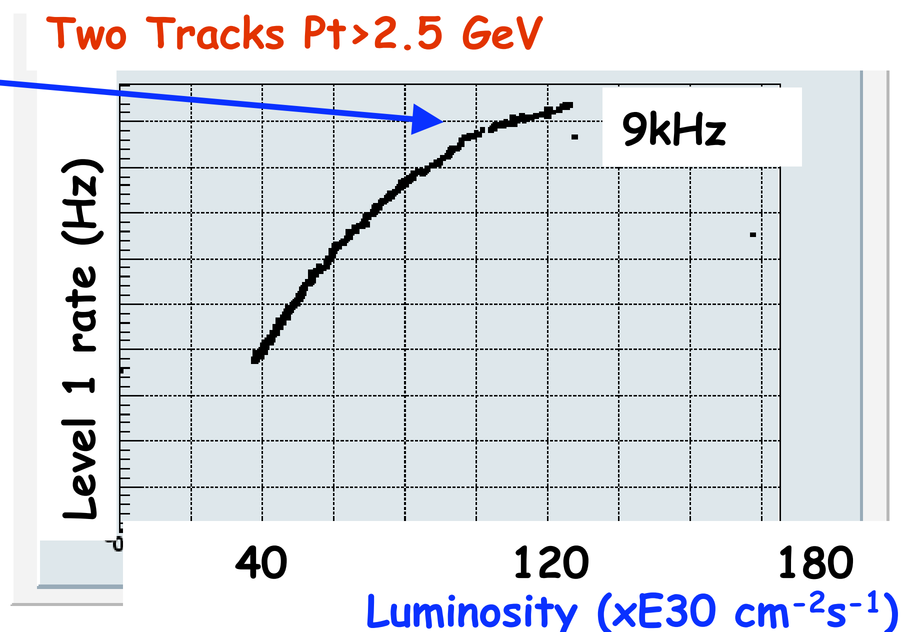
- More complex events, larger L2 processing time

- Luminosity is increasing, conditions will get worse.

Many ideas needed

Purity is the key @ high lum

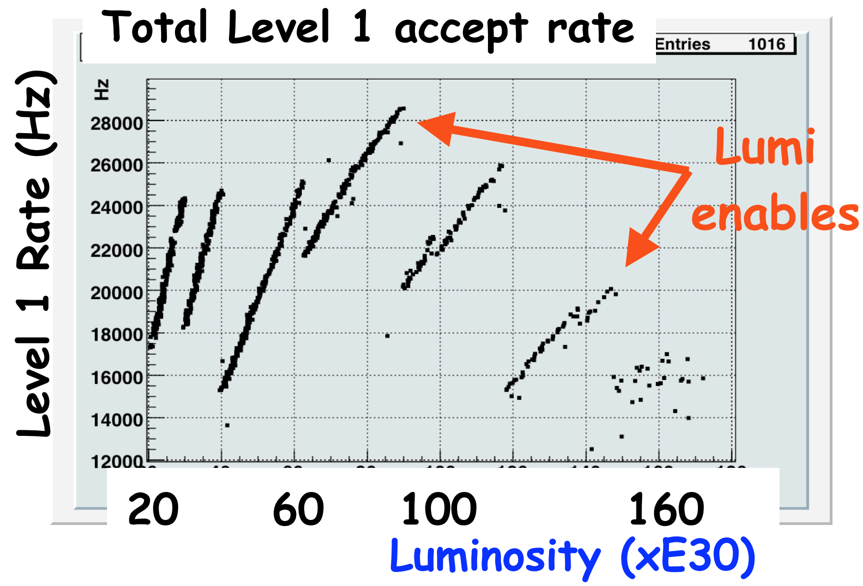
- Two Track Trigger rate much higher than bandwidth
  - Fortunately high signal xsec.
  - Give up efficiency for better purity, i.e. max yield @ high lumi
- Use luminosity counters to veto high multiplicity events --> less fakes --> higher purity



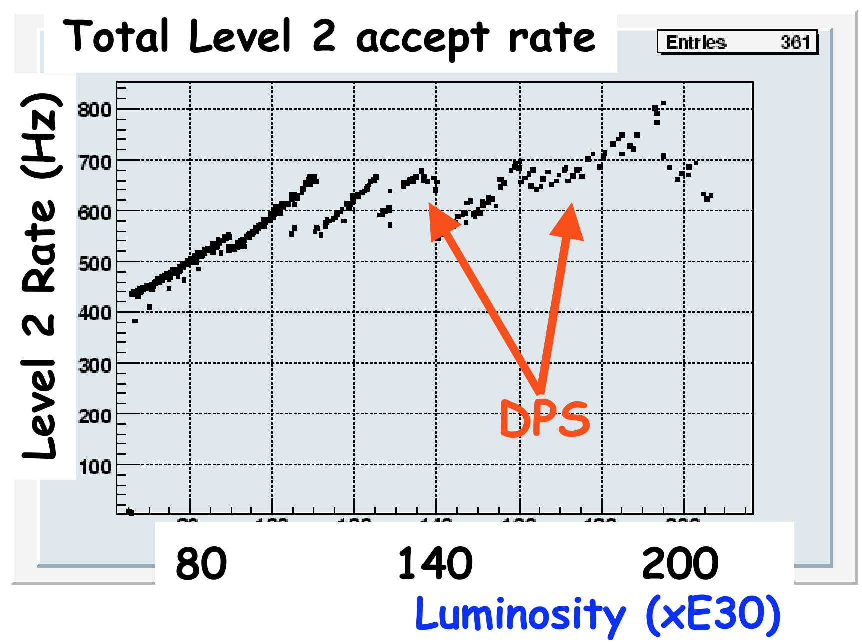
- Transverse Mass cut @ L1 for TwoTrackTrigger
- Use of more selective triggers such as TwoTrack + Lepton (higher tagging efficiency)
- Trigger Upgrades --> increase bandwidth --> reduce fakes & trigger rates

Fill in bandwith @ low lumi

- Enable triggers as b/w becomes available
  - Luminosity enable
  - Activate triggers below fixed lumi



- Dynamical change of PreScales
  - fill bandwidth on the fly
- Uber Prescale
  - accept low purity events
  - only when DAQ mostly idle

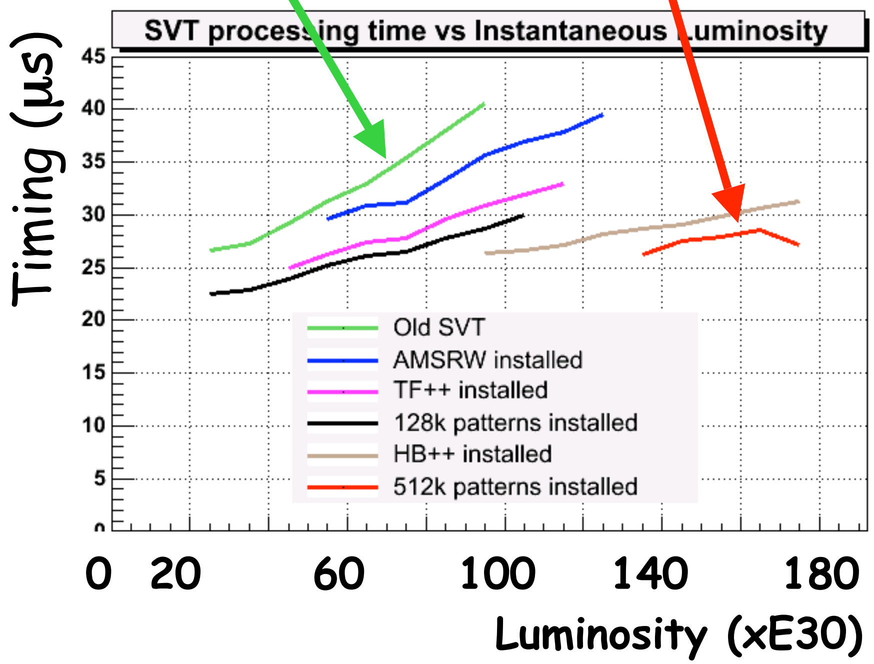


SVT Upgrade (done, fall 2005)

- Need to process more complex events in less time
- Same architecture as original system
- Better pattern recognition resolution
  - New AM chip
    32K→512K patterns
  - fewer combinations/road
- Faster components
  - Use custom but general purpose
    Pulsar boards
    http://hep.uchicago.edu/~thliu/projects/Pulsar/
  - Short development time

original system

upgraded system



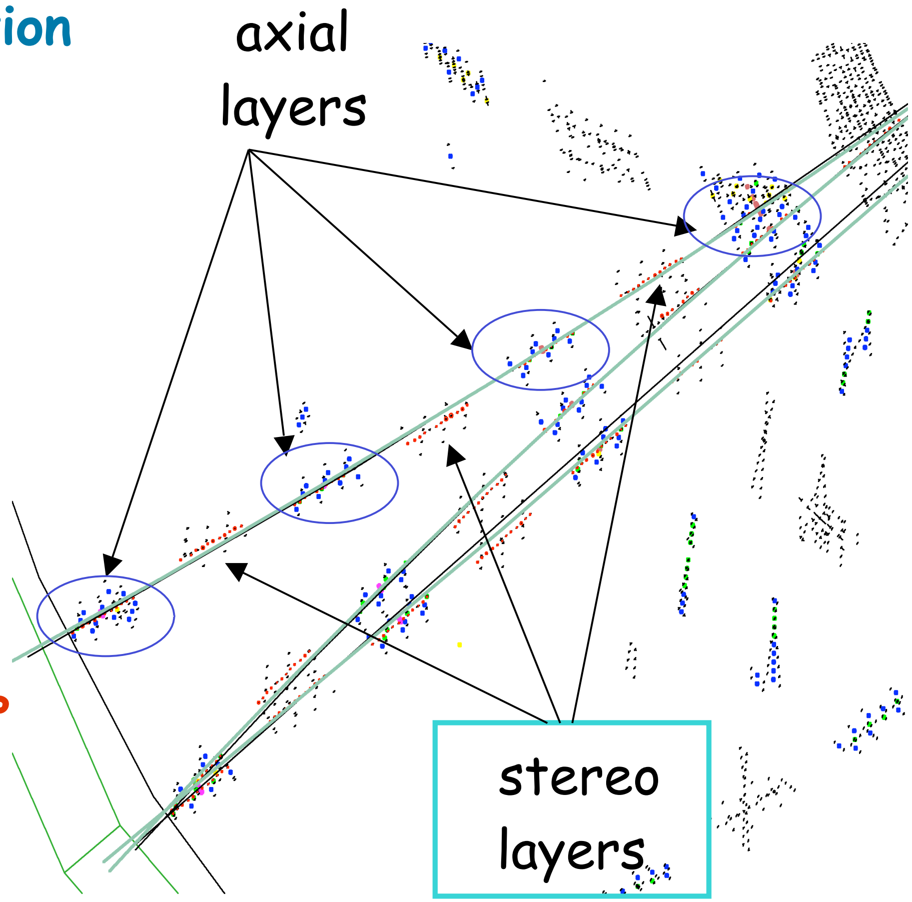
NSS2005 Conf. Rec. Vol.1, 603

L1 bandwidth 18kHz -> 30kHz
Now stable w.r.t luminosity

Take good data @ high lumi & more data @ low lumi

XFT Upgrade (almost ready)

- Add a stereo tracking path to the existing axial one
  - level 1: require stereo confirmation
    - reduce fake rate
  - level 2: fit stereo segments
    - further reduce fake rate
    - measure z0 and ctg(θ)



- The system is now fully installed
  - commissioning in progress
  - preliminary performance
    - stereo confirmation eff. 96%
    - fake rejection 4-10
      being optimized

Take good data @ high lumi & more data @ low lumi

Conclusions

We reviewed

The CDF detector elements crucial for B Physics trigger

- Tracker
- Lepton detectors (muon chambers, CEM calorimeter)

The CDF Trigger architecture

XFT: Level 1 track trigger (lepton triggers)

SVT: Level 2 silicon vertex trigger

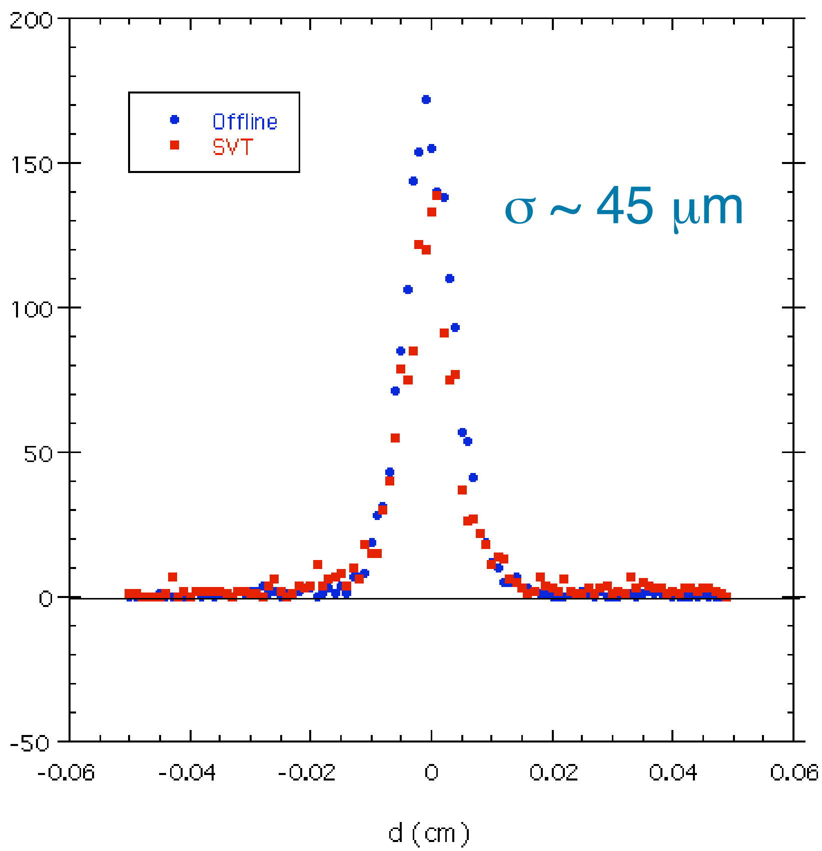
The CDF Trigger strategy for B Physics

Problems/solutions for high luminosity running

CDF can take good data for B analyses for all Run II

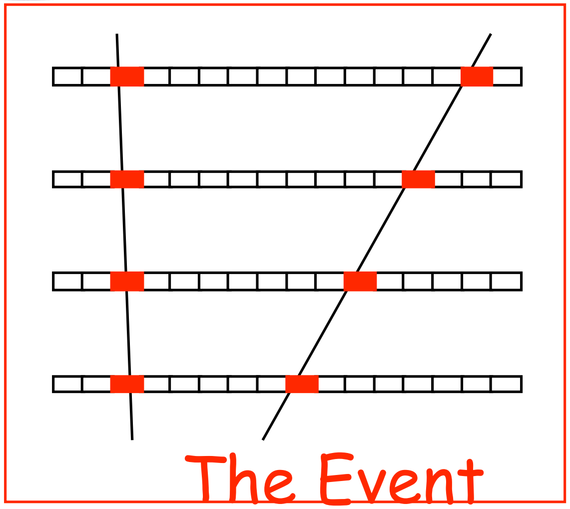
BACKUP

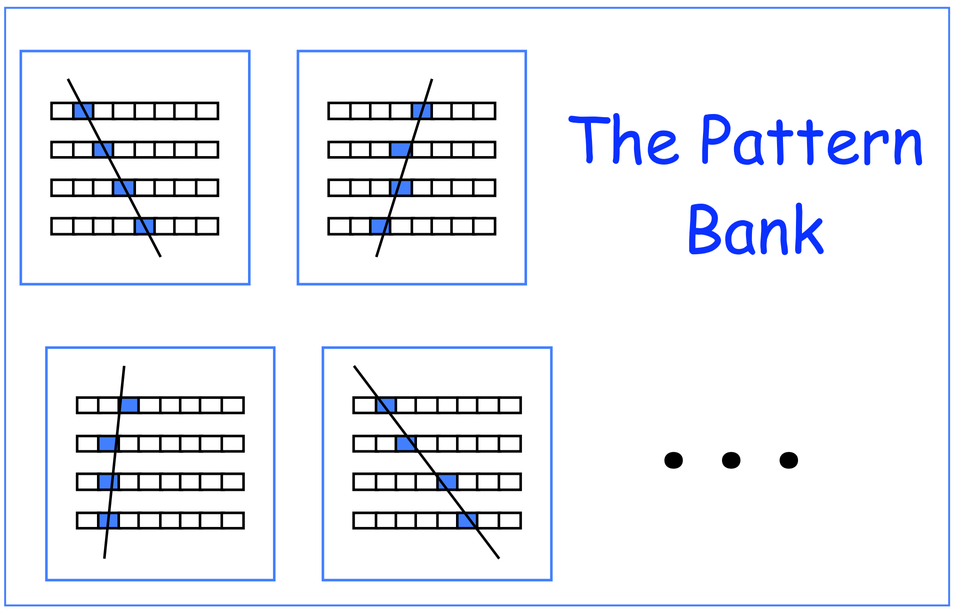
Promise is promise

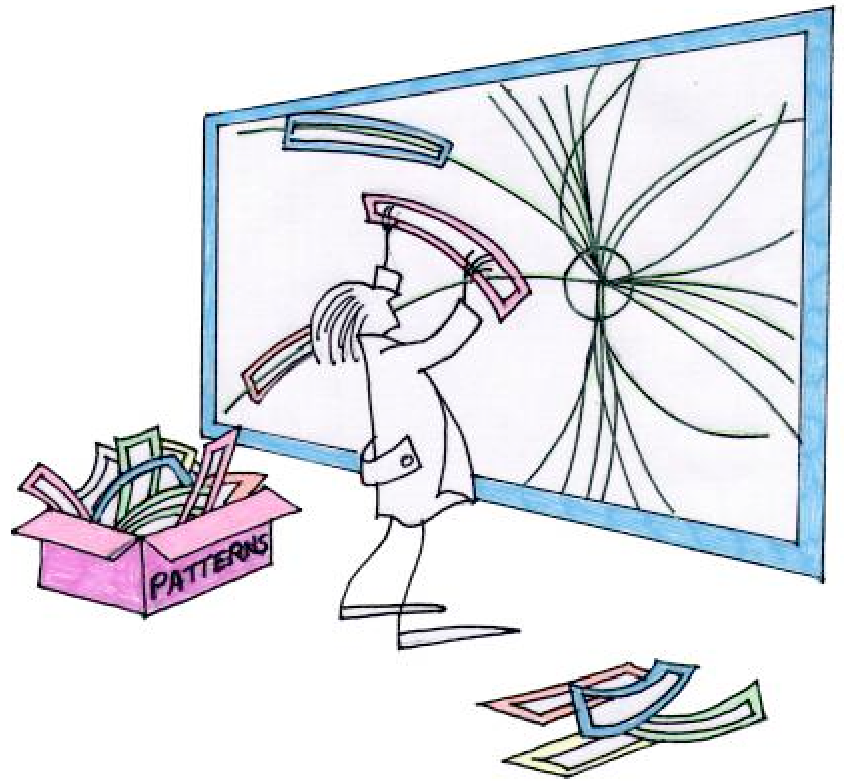


What we promised…. From SVT TDR ('96) using offline silicon hits and offline CTC tracks

Pattern matching







24 AM++ installation

- 2 AM++ per 30 degrees
- 512k patterns
- pattern width 240μm
  - was 600μm with 32kpatt.

Currently using 512k patterns for maximum speed.

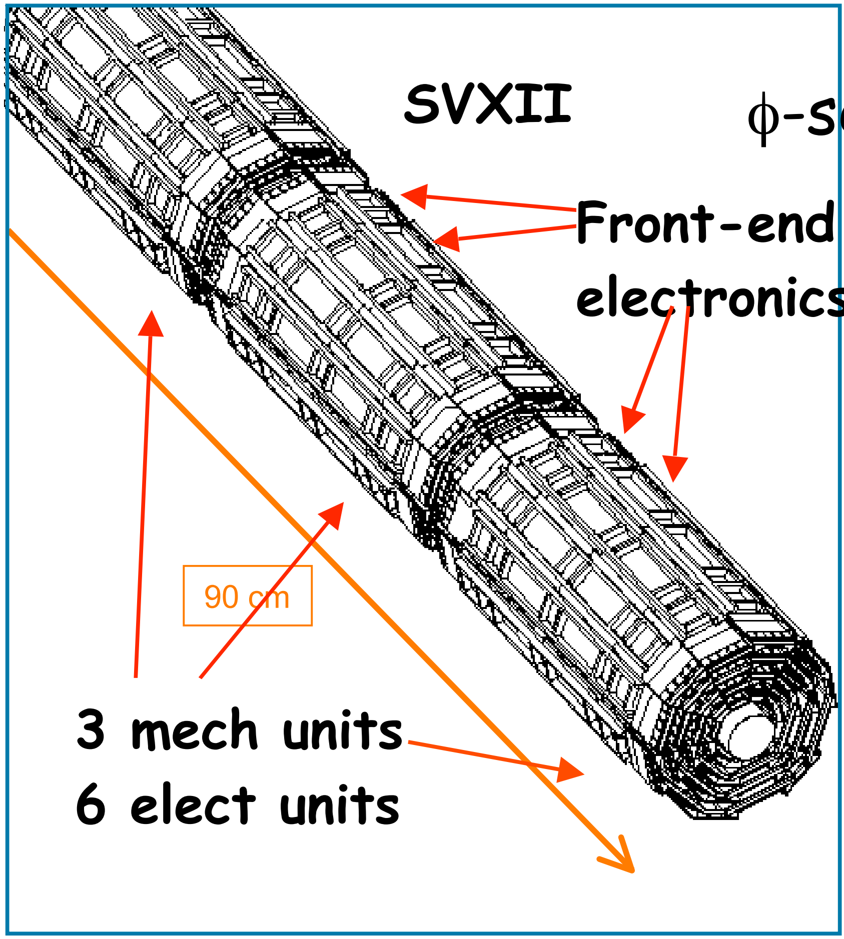
Extend tracking applications:

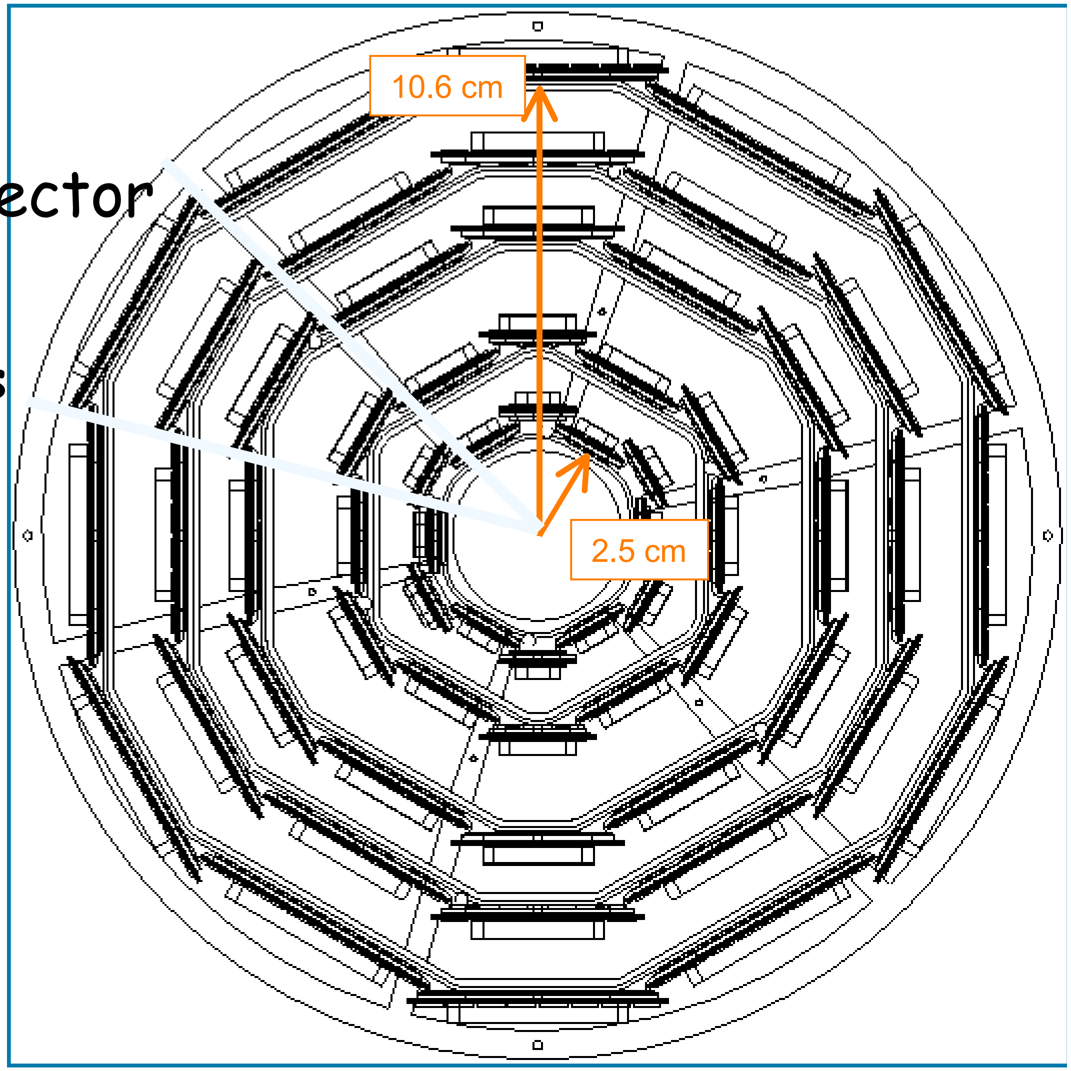
- release upper I.p. cut
- Pt down to 1.5GeV

	<# of fits>	RMS # fits
32k patt	32	42
128k patt	20	32
512k patt	12	18

Lumi = 100E30 $cm^{-2}s^{-1}$

SVXII: silicon vertex detector



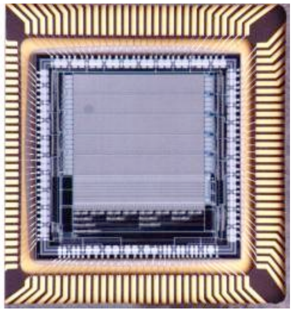


New AM chip

- Parallel pattern recognition is performed
  by the Associative Memory
  an array of AMchips

- Pattern recognition happens during detector readout!

Original AM chip



- Standard Cell UMC 0.18 μm
  10x10 mm die - 5000 patterns (was 128)
  6 input hit buses (4Gbit/s)
  tested up to 40 MHz, simulated up to 50 MHz

- 3000 production chips on April 2005
  good yield 70%

2nd step: Track Fitting

- Track confined to a thin pattern: fitting becomes easy
- Linear expansion in the hit positions x_i:
  - Chi2 = Sum_k ($(c_{ik}\ x_i)$^2)
  - $d = d_0 + a_i\ x_i$; $phi = phi_0 + b_i\ x_i$; Pt = ...
- Fit reduces to a few scalar products: fast evaluation
  - (DSP, FPGA …)
- Constants from detector geometry
  - Calculate in advance
  - Correction of mechanical alignments via linear algorithm
    - fast and stable
    - A tough problem made easy !

Constraint surface

6 coordinates: x_1, x_2, x_3, x_4, x_5 (P_T), x_6 (ϕ)

3 parameters to fit: P_T , ϕ , d

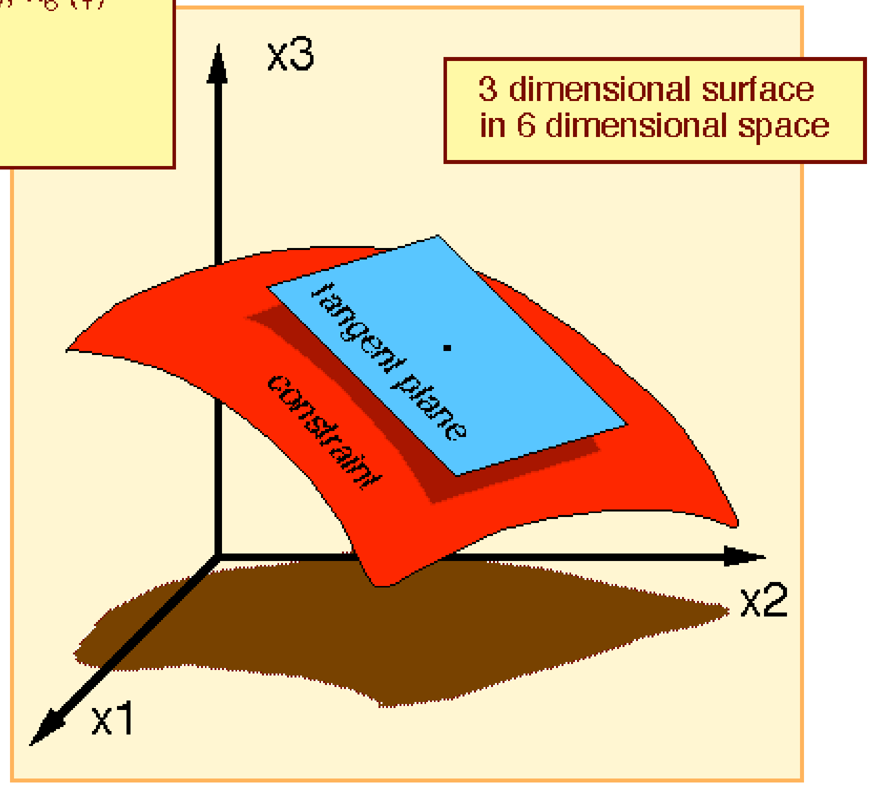
3 constraints

tangent plane:

$$\sum_{1}^{6} a_i x_i = b$$

track parameters:

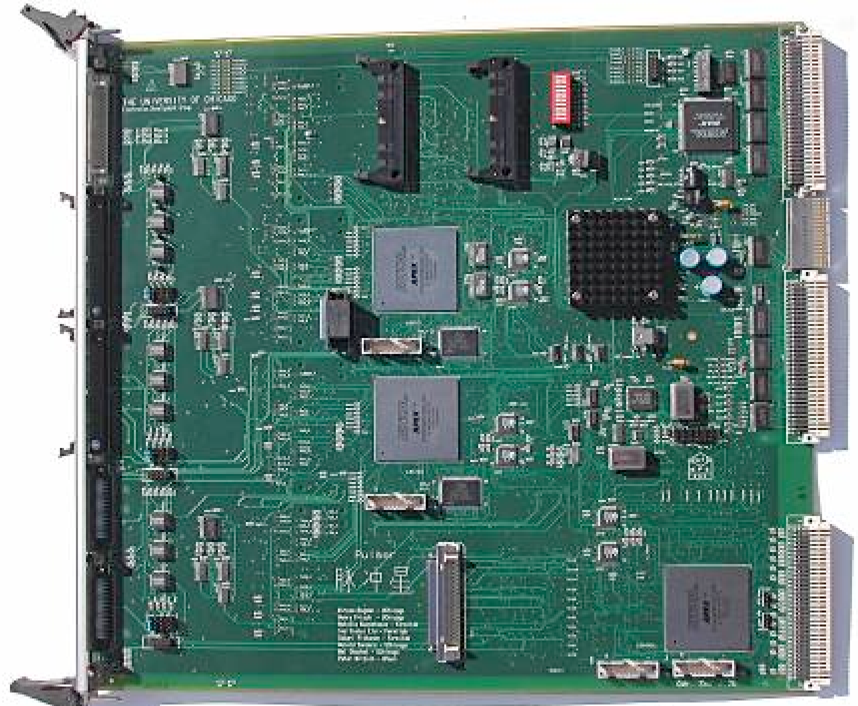
$$d \approx c_0 + \sum_{1}^{6} c_i x_i$$



Linear approximation is so good that a single set of constants is sufficient for a whole detector wedge (30° in ϕ)

Pulsar in SVT++

Implement new boards with Pulsars:
- Fast enough to handle the new amount of data
- SVT interface built in
- Developers can concentrate on firmware (= board functionalities)



Pulsar PCB, top side

The Pulsar board is a programmable board:

3 powerful FPGAs

embedded RAM

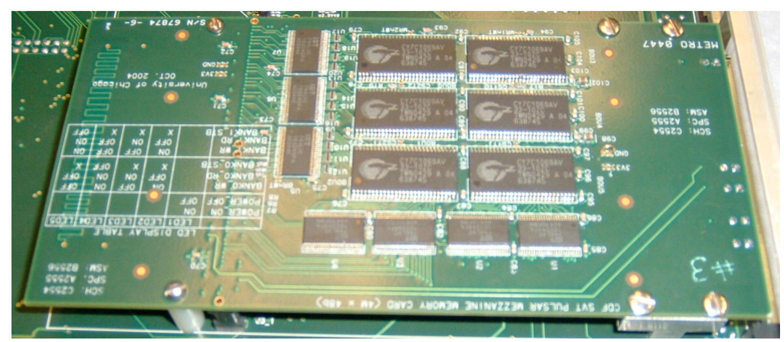
all CDF connectors

modular mezzanines

S-link I/O

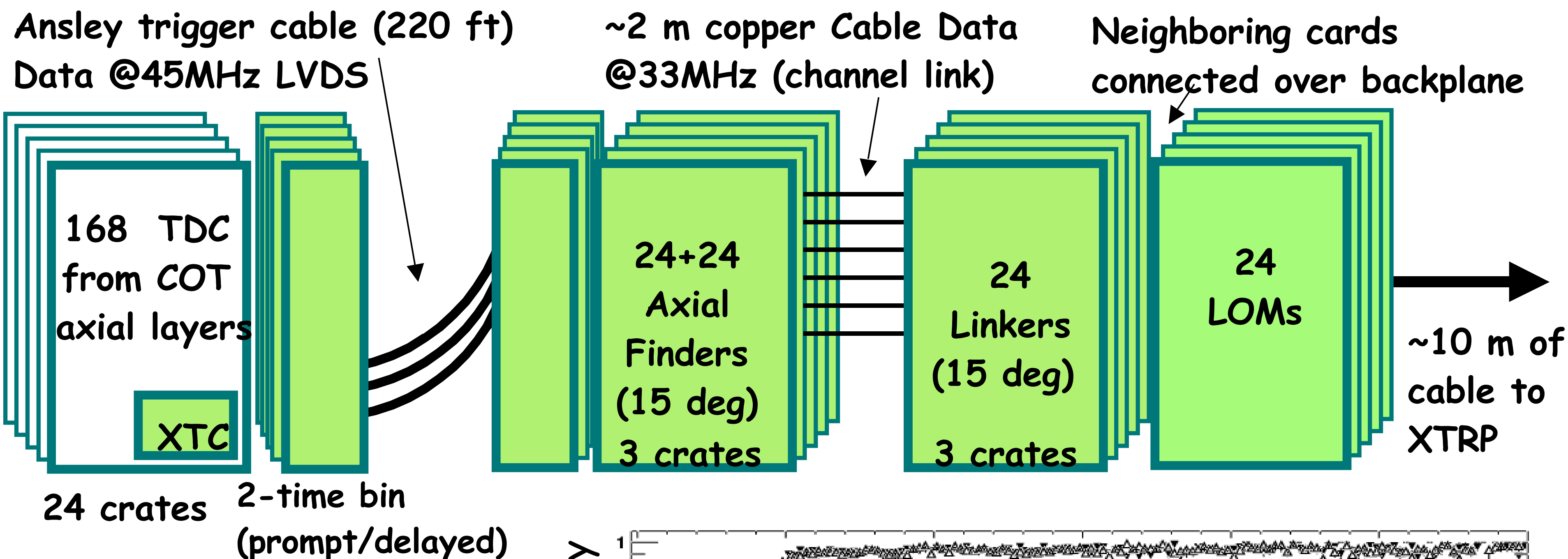
RAM extension

RAM mezzanine 4Mx48bits



Pulsar @ CDF --> FPGAs @ board devel.

XFT Architecture

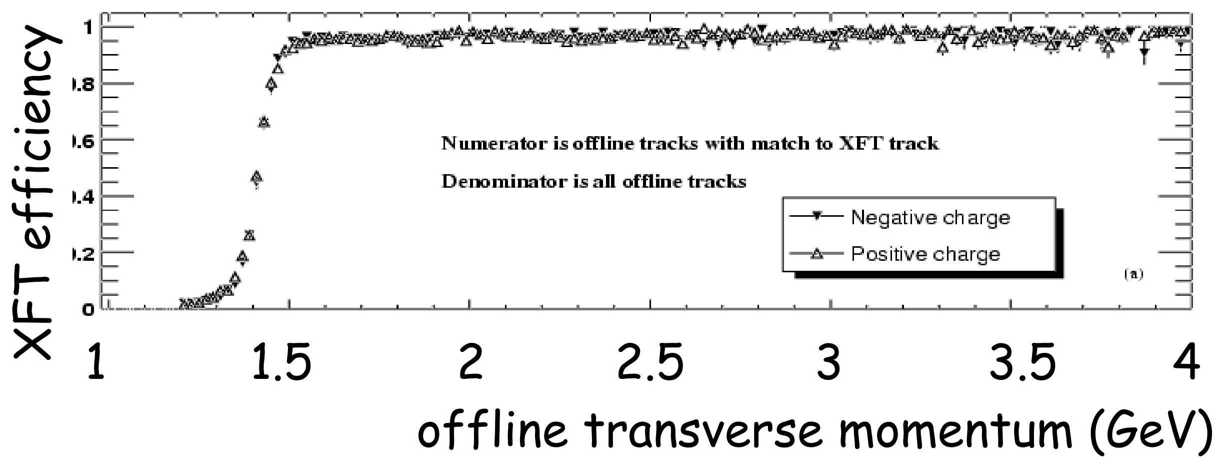


$\sigma(1/p_T)$ = 1.7%/GeV

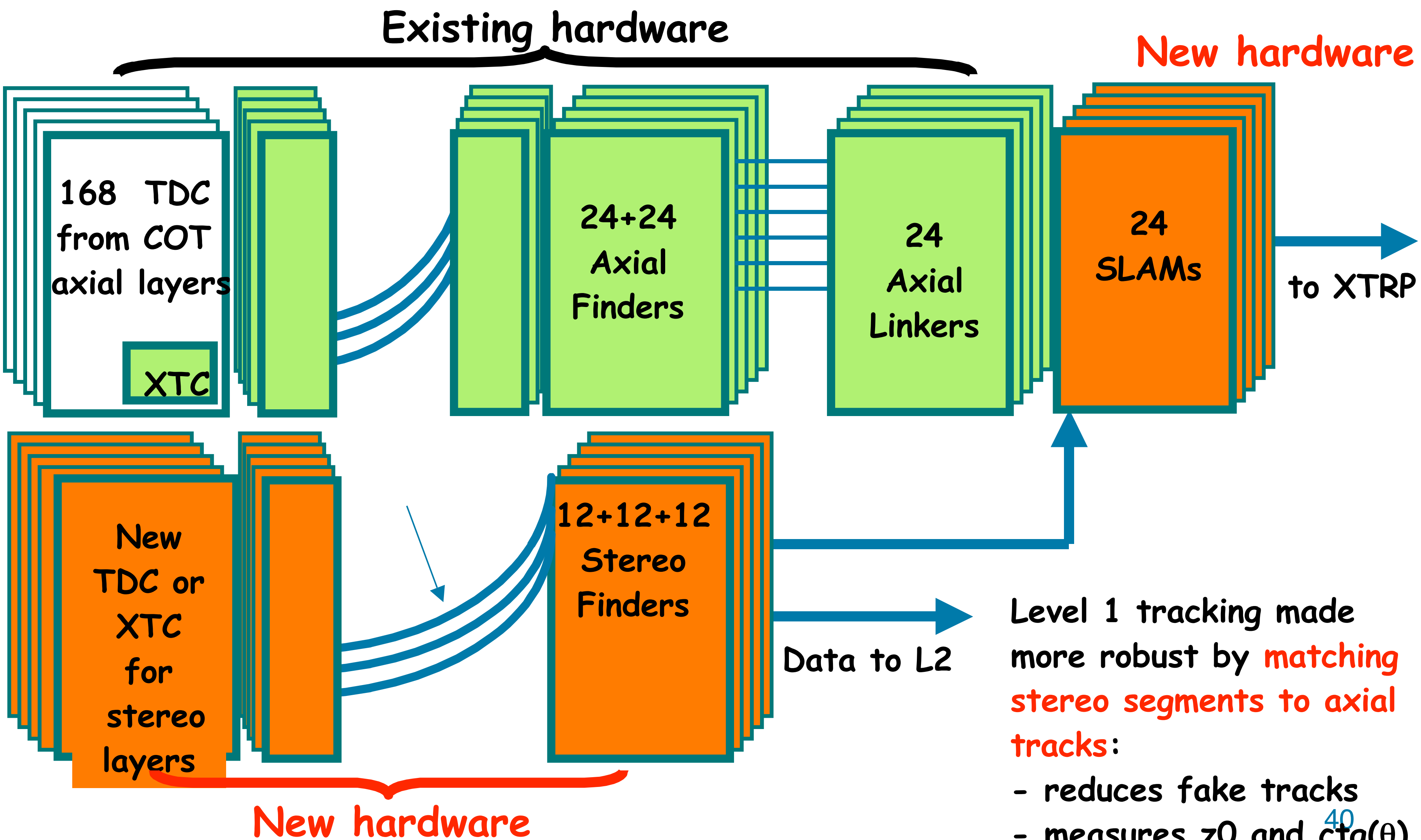
$\sigma(\phi_0)$ = 5 mrad

96% efficiency

(p_T > 1.5 GeV)



XFT Upgrade (within summer 2006)



Level 1 tracking made more robust by matching stereo segments to axial tracks:

- reduces fake tracks
- measures z0 and ctg(θ)